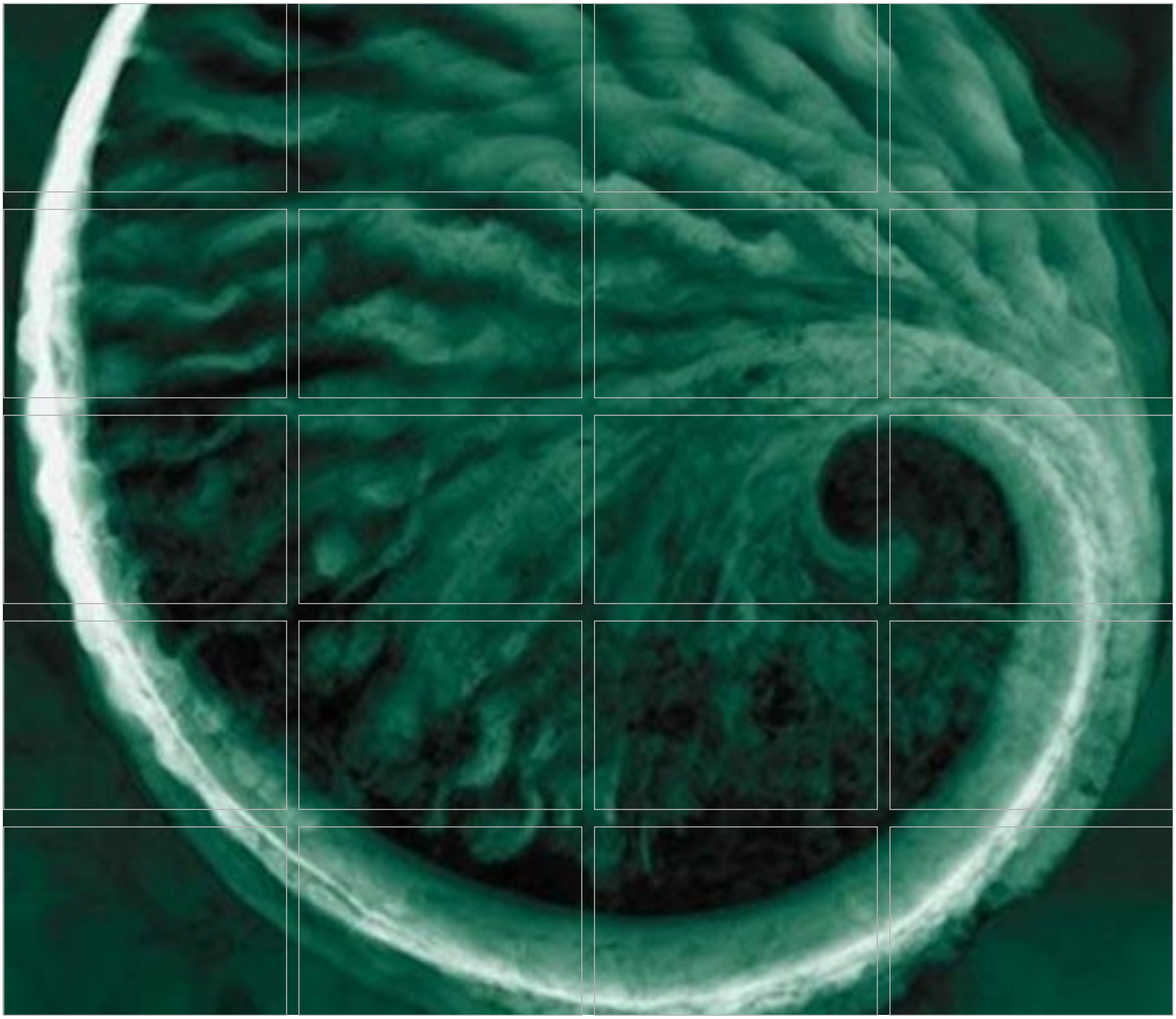

Life Cycle Assessment (LCA) of BlazeMaster® Fire Sprinkler System

FINAL REPORT

July 2010

The Lubrizol Corporation

Life Cycle Assessment (LCA) of BlazeMaster® Fire Sprinkler System

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For and on behalf of Environmental Resources Management

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Signed:

Position: Partner

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EXECUTIVE SUMMARY

The Lubrizol Corporation (Lubrizol) commissioned Environmental Resources Management Limited (ERM) to perform a cradle-to-grave life cycle assessment (LCA) assessing the environmental performance of BlazeMaster® post-chlorinated polyvinyl chloride (CPVC) piping used in light hazard fire protection applications, in accordance with United States National Fire Protection Agency (NFPA) 13.

The study has been peer reviewed and is fully compliant with international standards.

The results of this study are intended to support the publication of articles and marketing literature detailing the environmental profile and performance of BlazeMaster®.

STUDY OBJECTIVES

The main objectives of the LCA are two-fold:

1. to support the publication of articles and marketing literature detailing the environmental profile and performance of CPVC piping; and
2. to create a foundation for more detailed future analyses (eg different material thicknesses, additional materials and applications).

GENERAL CONCLUSIONS

The principal recommendation with regard to lowering the overall life cycle impacts of BlazeMaster® is for Lubrizol to work with its suppliers to identify areas where efficiency can be improved. Only a small proportion of the impacts associated with BlazeMaster® arise from Lubrizol's own facility, and therefore the focus should be on improvements with raw material suppliers and ensuring best practices are in place with the pipe and fittings conversion facility.

ABOUT LCA

ISO standards 14040 and 14044 on LCA advocate critical review to facilitate understanding and to enhance the credibility of an LCA. In line with the standards, this study underwent external critical review. The reviewer's Critical Review Statement, the commissioners' comments and ERM's responses to the points raised therein, are included in the final report.

The purpose of a critical review is to ensure that:

- the methods used to carry out the LCA are consistent with ISO 14040ff;
- the methods used to carry out the LCA are scientifically and technically valid;
- the data used are appropriate and reasonable in relation to the goal of the study;
- the interpretations reflect the limitations identified and the goal of the study; and
- the study report is transparent and consistent.

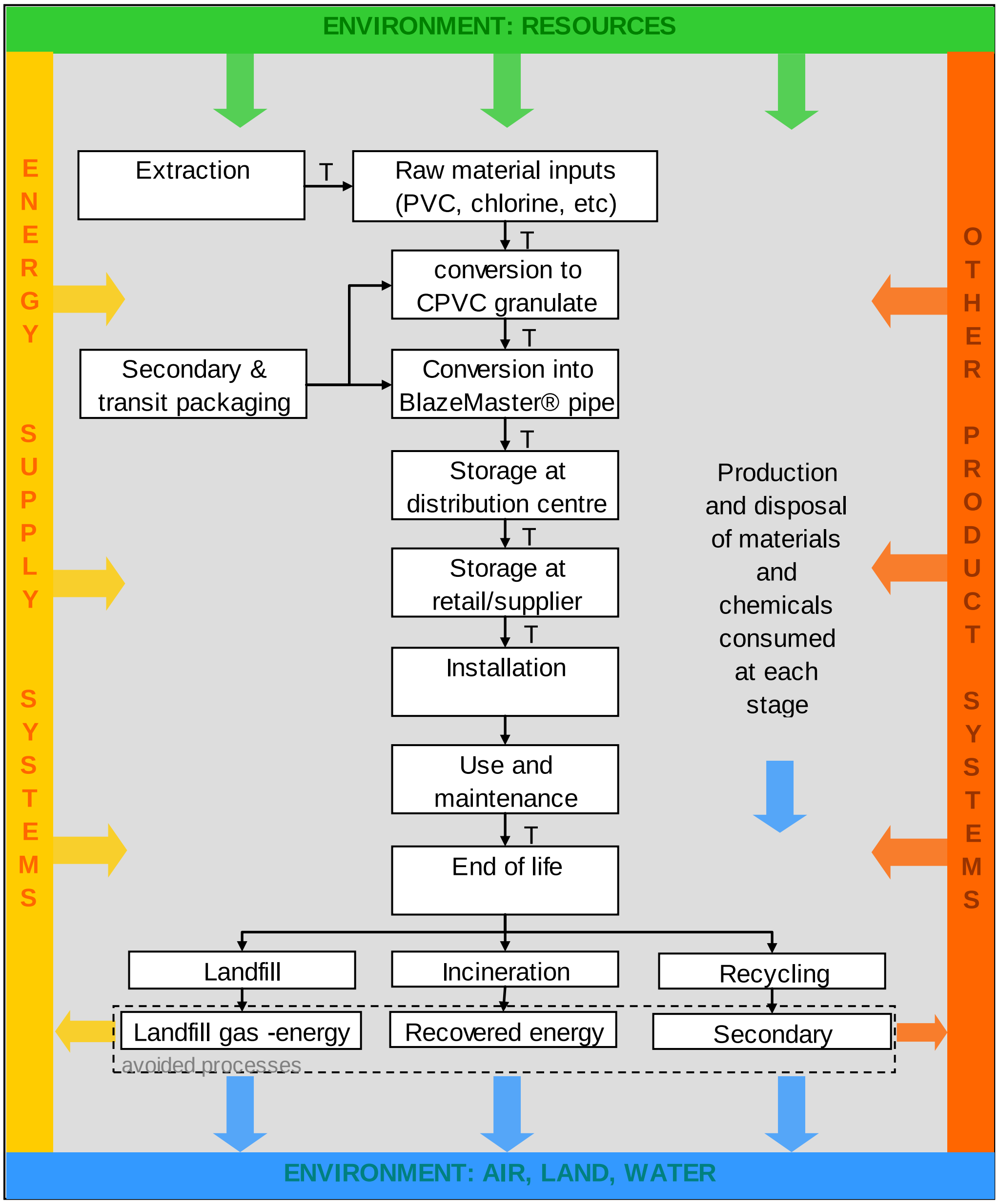
The critical reviewer is Professor Dr Walter Klöpffer, Editor-in-Chief of the International Journal of Life Cycle Assessment.

LCA OF BLAZEMASTER®

This study followed a cradle-to-grave LCA approach. This means that all significant life cycle stages related to the product studied were considered, from raw material extraction, through processing and production, to distribution, use, waste collection, recycling or final disposal. Energy and material inputs were traced back to the extraction of resources, and emissions and wastes from each life cycle stage were quantified.

A general flow diagram summarizing the life cycle stages and system boundaries for the BlazeMaster® pipe is provided in *Figure 1*.

Figure 1 Summary system boundary flow diagram



T - transport

Impacts studied

The nature of the fossil-based product system means that it will incur environmental burdens across the impacts associated with petro-chemical product systems. The environmental indicators and impacts listed below cover the main issues identified and documented.

- Resource depletion (metal and fossil depletion)
- Acidification

- Eutrophication
- Climate change (Global Warming Potential over 100 years [GWP 100])
- Ozone layer depletion
- Human toxicity
- Fresh water ecotoxicity
- Terrestrial ecotoxicity
- Photo-oxidant formation
- Water depletion
- Energy consumption

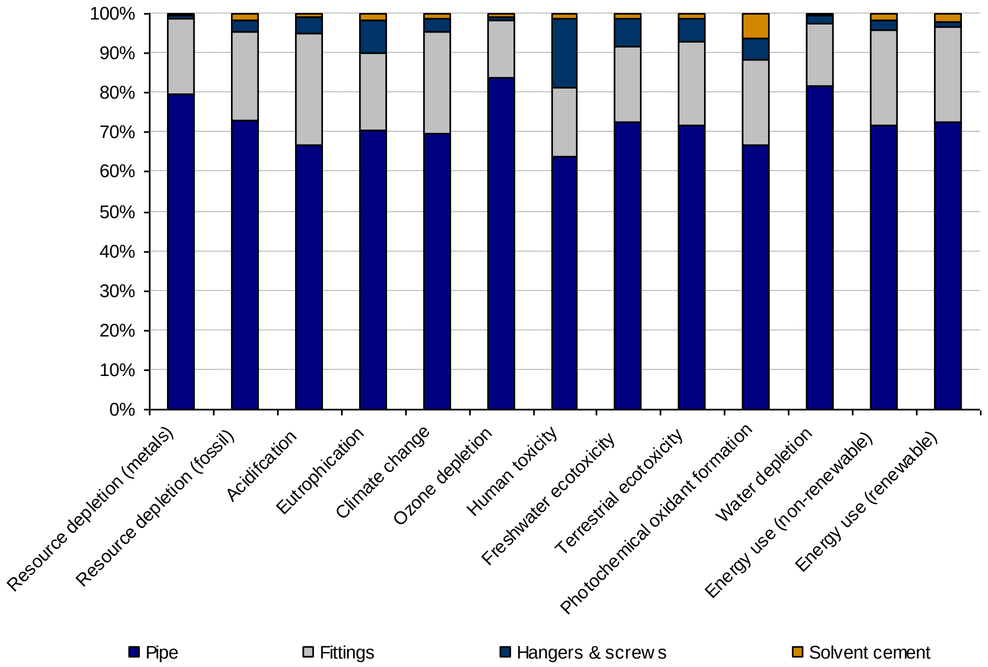
The study was delivered using a high proportion of primary data and is considered to be both a robust and an accurate representation of the environmental impacts of Lubrizol's BlazeMaster® fire sprinkler system. Data quality requirements, as defined by ISO 14044, are based on the ISO standard on goal and scope definition and inventory analysis. The results can be used as a foundation for more detailed future analyses that may explore design changes and applications.

CONCLUSIONS

The key messages that can be extracted from the results are summarized below and depicted in *Figure 2*.

- **Raw material production** is the **most significant contributor** to all impact categories, with the exception of freshwater ecotoxicity.
- **Manufacturing** is the second most significant contributor, accounting for up to 29% of the total impact.
- Disposal of **PVC in landfill** influences toxicity impact categories.
- The impact from wholesale, transport and packaging is very low.

Figure 2 Data summary



RECOMMENDATIONS

Working with suppliers to identify areas where efficiency can be improved is fundamental to lowering the overall life cycle impacts of BlazeMaster®. Only a small proportion of the impacts arise at Lubrizol's own facility, and therefore the focus should be on improvements with raw material suppliers and ensuring best practices are in place with the pipe and fittings conversion facility.

In addition, there is little in the way of improvements that can be made in the installation, use, maintenance and removal stages for BlazeMaster®, as these stages of the life cycle have virtually no impact. Further efforts to reduce waste during installation can be commended, but would have little influence on the overall environmental impacts of the BlazeMaster® system. Improvement opportunities exist at end of life, were recycling to be implemented – and this is discussed below.

Climate change and carbon footprinting

Using alternative energy sources and reducing greenhouse gas emissions are key challenges for industry. Efforts to reduce contributions to climate change should focus on the selection of raw materials with lower embedded carbon and on increasing efficiency in manufacturing processes. One method of selecting products with a lower carbon footprint would be to consider the use of recycled products, such as recyclate or by-products from other processes.

The transport of raw materials does not have a significant impact on the global warming results. However, choosing suppliers who manufacture locally, if possible, is under Lubrizol's direct control and would deliver marginal improvements.

Greatest potential for environmental improvement

Beyond improvements in the supply chain, analyzing life cycles and reuse/recycle possibilities offers the potential to reduce environmental impacts. A sensitivity analysis conducted clearly shows the benefits of recycling and that the more that is recovered, the better. Exploring State-level initiatives to recycle construction and demolition waste, and promoting the inclusion of CPVC in these programs, could open up opportunities to reduce impacts at end of life.

Although not included in this assessment, research into the inclusion of recyclate in the production of BlazeMaster® may also offer further opportunities to reduce the environmental impacts of the product system.

1 INTRODUCTION

1.1 BACKGROUND TO THE STUDY

The fire sprinkler market changed dramatically in 1984, when the market's first non-metallic fire sprinkler system was created. Marketed under the BlazeMaster® brand name, the product soon proved to be an alternative to traditional metallic systems.

BlazeMaster® pipe and fittings are designed specifically for fire sprinkler systems. They are made from a specialty thermoplastic known chemically as post-chlorinated polyvinyl chloride (CPVC). Today, it is the most specified non-metallic fire sprinkler system in the world approved for both residential and light commercial applications. It has been installed in a wide array of applications—from single-family homes to high-rise buildings, hotels, college dormitories and numerous healthcare facilities—in more than 60 countries across the globe.

Key to the product's success is its cost effectiveness. With material costs that are more stable than the cost of traditional metal, a BlazeMaster® CPVC fire sprinkler system also yields significant labor savings because it offers a faster, easier installation process. An easy joining system eliminates the need for an open torch. This process is not only faster and more cost-efficient, but it is also highly reliable, safer and cleaner. These benefits are especially critical for commercial retrofits, in which faster installations and easier clean-up translate into higher occupancy rates.

From a long-term reliability standpoint, BlazeMaster® CPVC pipe and fittings also offer corrosion resistance (including resistance to microbiologically influenced corrosion [MIC]), superior hydraulics, high heat tolerances and superior flame and smoke characteristics.

This study was commissioned further to understand the environmental impacts of BlazeMaster® CPVC pipe and fittings.

1.2 PROJECT STAKEHOLDER GROUP

The study was supported by an internal Lubrizol project stakeholder group that informed the study and contributed data, including:

- Matthew Kuwatch;
- Terry Thiele;
- Stan Nerderman;
- Christopher Zook;

- Tina Massel;
- Kurt Logsdon;
- Jeff Gibson;
- Sinikka Freidhof; and
- John Quackenbush.

2 GOAL AND SCOPE

2.1 GOAL OF THE STUDY

ERM performed a cradle-to-grave life cycle assessment (LCA) assessing the environmental performance of BlazeMaster® CPVC piping used in light hazard fire protection applications, in accordance with United States National Fire Protection Agency (NFPA) 13.

2.1.1 *Intended application*

The results of this study are intended to support the publication of articles and marketing literature detailing the environmental profile and performance of CPVC piping.

2.1.2 *Intended audience*

The report is presented in a format that will allow for Lubrizol to use it in external communication, particularly for communication on the environmental impacts of fire sprinkler systems.

As the results may be used externally, it is a requirement that the study undergoes a critical review.

2.1.3 *Reasons for completing the study*

The main goals of the LCA are two-fold:

1. to support the publication of articles and marketing literature detailing the environmental profile and performance of CPVC piping; and
2. to create a foundation for more detailed future analyses (eg different material thicknesses, additional materials and applications).

2.2 SCOPE OF THE STUDY

2.2.1 *Product system considered*

The functional unit used in this study was 1000 feet (304.8 meters) of piping with a useful lifetime of 50 years (1). The scope of the study followed the cradle-to-grave format. However, to maximize usefulness, cradle-to-gate results were also generated (both life cycle inventory and impact assessment), as customers often request impact profiles and data up to the point at which they accept a product.

(1) BlazeMaster® is designed to a 50-year life expectancy with a safety factor of two (www.blazemaster.com).

The CVPC compound is produced in Louisville, Kentucky. Thereafter, it is transported to [the manufacturer's facility] for conversion to CPVC piping. The finished product is distributed throughout the US.

2.2.2 *Function of the pipe*

BlazeMaster® pipe and fittings are designed specifically for fire sprinkler systems.

2.2.3 *Functional unit*

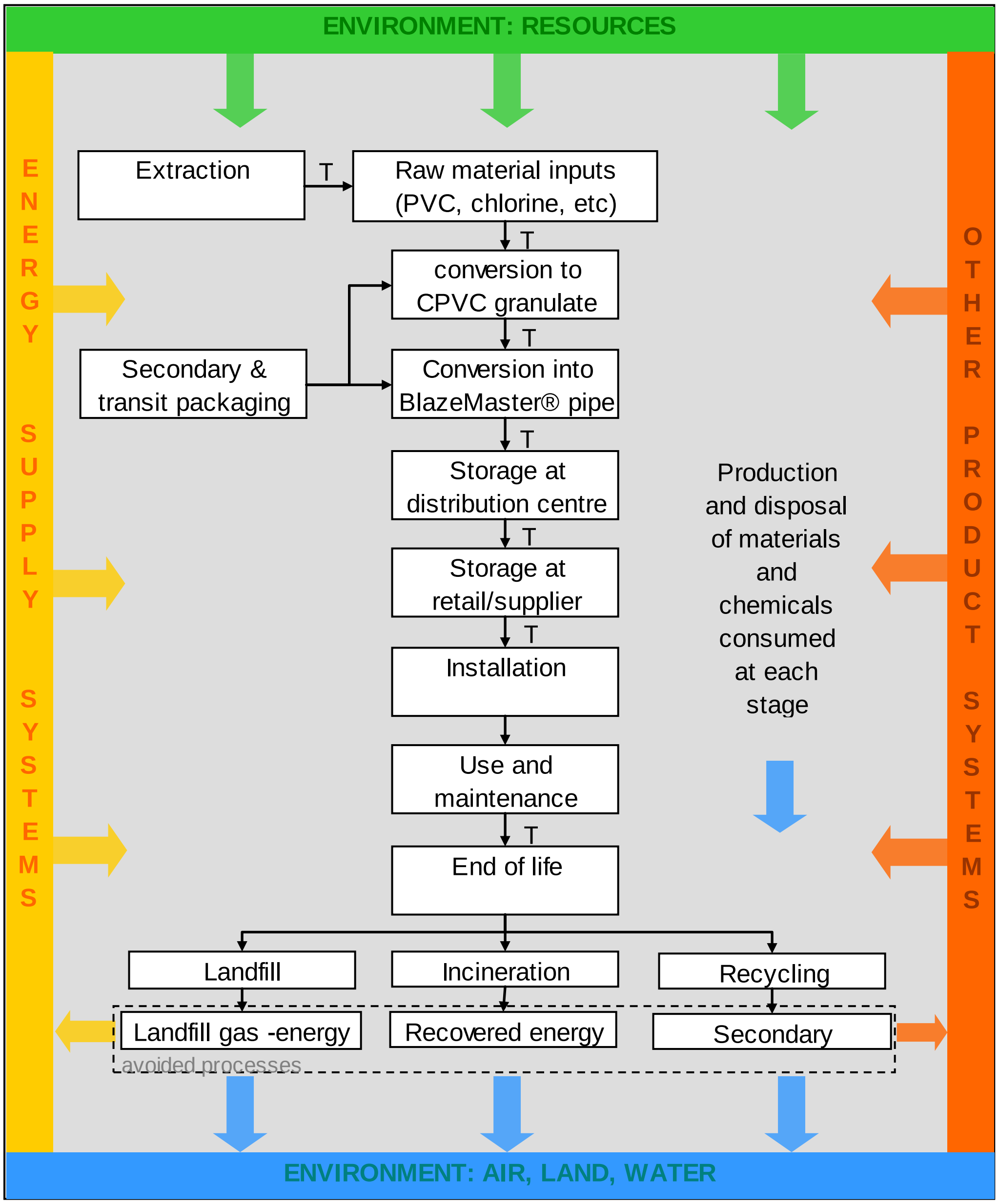
The functional unit of the study was 1000 feet (304.8 meters) of piping used in a high rise multi-residential dwelling in the United States for a 50 year time period.

2.2.4 *System boundaries*

This study followed a cradle-to-grave LCA approach. This means that all significant life cycle stages relative to the product studied were considered, from raw material extraction, through processing and production, to distribution, use, waste collection, recycling or final disposal. Energy and material inputs were traced back to the extraction of resources, and emissions and wastes from each life cycle stage were quantified.

A general flow diagram summarizing the life cycle stages and system boundaries for the BlazeMaster® pipe is provided in *Figure 2.1*.

Figure 2.1　*Summary system boundary flow diagram*



T - transport

The following life cycle steps were included within the system boundaries (unless excluded as falling below the cut-off criteria):

- raw material extraction and production (PVC, chlorine, etc);
- transportation of raw materials to CPVC production facility;
- conversion of materials into CPVC granulate;
- production of secondary and transit packaging for delivery of CPVC granulate to BlazeMaster® production facility;

- transportation of CPVC granulate and other materials to BlazeMaster® pipe conversion;
- conversion into BlazeMaster® pipe;
- production of secondary and transit packaging for delivery to regional distribution centre (RDC);
- distribution of the BlazeMaster® pipe to RDC;
- storage at RDC;
- distribution of the BlazeMaster® pipe to retail/supplier;
- storage at retail/supplier;
- transportation of the BlazeMaster® pipe to the installation site;
- installation of BlazeMaster® pipe at site;
- use and maintenance of BlazeMaster® pipe over useful life;
- removal of BlazeMaster® pipe from site at end of useful life; waste collection and waste management (1);
- avoided processes from energy recovered from captured landfill gas, energy recovered through energy from waste, secondary materials recovered through recycling, recycling system expansion and displacement of virgin material;
- production of fuels and electricity consumed by processes; and
- production and disposal of materials and chemicals consumed at each stage.

Life cycle stages that were omitted from the scope of the study include:

- capital burdens relating to production and disposal of infrastructure such as roads, machines, buildings, etc.

Life cycle stages included

Raw material production

The production of raw materials such as plastics, chlorine, steel and aluminum was included in the study. The extraction of resources and their processing was included. This covered material and energy consumption during extraction and processing, as well as the emission of substances and waste.

Data for the production of PVC was sourced from the American Chemistry Council's 2007 report entitled *Cradle-to-Gate Life Cycle Inventory of Nine Plastic Resins and Two Polyurethane Precursors* that was written by Franklin Associates. The data for production of chlorine was directly sourced from the supplier.

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(1) The 2004 European Commission report, Life Cycle Assessment of PVC and of Principal Competing Materials, states that provided that landfills are operated appropriately and responsibly in accordance with present technical regulations, landfilling is an acceptable intermediate disposal option for PVC products. The report also notes that degradation of the PVC polymer was not observed.

Transport of raw materials to CPVC production facility

The transport from the raw material producer to the CPVC granulate producer was included. Where it was not possible to define specific distances, justifiable estimates were used.

CPVC granulate production

The conversion of raw materials into CPVC granulate was included in the study. The materials and energy used during production of the CPVC granulates ready for further conversion into pipe was included.

Production of secondary and transit packaging for transport to BlazeMaster® pipe production

The production of secondary and tertiary transit packaging used for transport between CPVC granulate production and BlazeMaster® pipe production was included in the study.

Transport of CPVC granulate to BlazeMaster® pipe production

The transport of the CPVC granulate to BlazeMaster® production facility was included. Where it was not possible to define specific distances, justifiable estimates were used.

Conversion into BlazeMaster® pipe

The production of the BlazeMaster® pipe from CPVC granulate and other materials was included in the study. Material, energy inputs, waste and emissions consumed by and produced by the BlazeMaster® pipe conversion process were included.

Transport of BlazeMaster® pipe to retail/supplier

The transport of the BlazeMaster® pipe from the production facility to the RDC was included. Where it was not possible to define specific distances, justifiable estimates were used.

Storage at retail/supplier

Energy use relating to the storage of the BlazeMaster® pipe at retail or supplier was included. Secondary data was used and allocated to the BlazeMaster® pipe. Wastage rates of the packaging and product during transport to, and at, retail were also sought. Where no specific data relating to the identified packaging systems could be collected, justifiable estimates were used.

Transportation of the BlazeMaster® pipe to the installation site

For transport to the installation site, the impacts of an example scenario were calculated based on estimates and available literature. Where transport to the installation site was found to contribute significantly to the overall environmental profile of the BlazeMaster® pipe, the estimated data were tested in a sensitivity analysis.

Installation of BlazeMaster® pipe at site

There are existing Guidelines for the installation of the BlazeMaster® pipe, and this method was followed when determining the environmental impact of installation. Where installation was found to contribute significantly to the overall environmental profile of the BlazeMaster® pipe, the estimated data were tested in a sensitivity analysis. The installation site was chosen to represent a typical Mid-West American State. For the purposes of the defining waste transportation distances and waste scenarios, Lubrizol chose Grand Rapids, Michigan, as this represents a typical market location.

Use and maintenance of BlazeMaster® pipe over useful life

A typical useful life of the BlazeMaster® pipe was determined based upon the defined functional unit, thus accounting for any necessary maintenance.

Removal of BlazeMaster® pipe from site at end of useful life

There are existing guidelines for removal of the BlazeMaster® pipe, and this method was followed when determining the environmental impact of removal. Where removal was found to contribute significantly to the overall environmental profile of the BlazeMaster® pipe, the estimated data were tested in a sensitivity analysis.

Collection of packaging waste

Generic data on the collection and transport of commercial waste to waste management facilities were included for the packaging being landfilled or incinerated. For the packaging being recycled, data were sought on its collection and transport to the waste recycling facilities. Where data were not available, justifiable estimates were used.

Waste management

Scenarios were developed based on the typical disposal methods of construction and demolition waste in the United States: landfill and recycling. Such data are reported by various State departments, and were used to model the scenarios. Where data were not available from government or industry statistics, the pipe removal companies were contacted for information. Incineration is not currently used as a way to manage this waste stream.

Infrastructure / capital burdens

Infrastructure (construction and demolition of plant, buildings, roads, vehicles etc) was not included in the study. The reason for excluding infrastructure, besides from practical aspects, is that, based on experience from previous LCAs, the contribution from these is negligible compared to the flows (eg the mass of materials, consumption of fuels and energy) included within the system boundaries in the time frame of the functional unit.

2.2.5 *Data and data quality requirements*

Data requirements

For the processes included within the system boundaries, all known inputs and outputs were included in the inventory. The data used were a combination of specific and generic data. Specific data were generally needed for the primary materials and for waste management. For the production of secondary materials, energy production, transport processes, generic data were used.

Specific data were sourced for:

- the production of PVC resin and chlorine;
- the production of CPVC compound;
- conversion to BlazeMaster® pipe;
- all packaging;
- retail (where applicable) and distribution;
- installation and removal;
- waste management scenarios; and
- transport distances and modes for all transport, unless stated as estimated in the system boundaries.

Secondary data, from published LCA and industry sources were manipulated for the specific product and market conditions assessed in this study and used for:

- production of additional raw materials used to manufacture the BlazeMaster® pipe;
- water inputs;
- fuels and electricity generation types;
- converting of raw materials;
- transport distances and types, if no data were available and already specified in the system boundaries; and
- specific waste management operations.

Data quality requirements

Data quality requirements are defined in *Table 2.1.* These are based on the ISO standard on goal and scope definition and inventory analysis.

Table 2.1 Data quality requirements

Parameter	Description	Requirement
Time-related coverage	Desired age of data and the minimum length of time over which data should be collected.	Data should represent the situation in 2008/09. Generic data and database data should represent the situation in 2008, and ideally not be more than 5 years old. In practice, data of up to 10 years and in some circumstances older data was possibly required. The age of the data was documented.
Geographical coverage	Area from which data for unit processes should be collected.	Data should be representative of the current US market.
Technology coverage	Technology mix.	Data should be representative of the technology currently used for the packaging as marketed in the US.
Precision	Measure of the variability of the data values for each data category expressed.	Specific and representative data were used in the study. Where there was potential variability in the data, a sensitivity analysis was used to determine its significance.
Completeness	Assessment of whether all relevant input and output data were included for a certain data set.	Specific datasets were benchmarked with literature data and databases. Simple data validation checks (eg mass balances) were performed.
Representativeness	Degree to which the data represent the identified time-related, geographical and technological scope.	The data should fulfill the defined time-related, geographical and technological scope.
Consistency	How consistently the study method was applied to different components of the analysis.	The study method was applied to all the components of the analysis.
Reproducibility	Assessment of the method and data, and whether an independent practitioner would be able to reproduce the results.	The information about the method and the data values should allow an independent practitioner to reproduce the results reported in the study. Please note this level of data is not likely to be provided in the final report.
Sources of the data	Assessment of data sources used.	Data were derived from credible sources and databases.

Source: ISO 14044:2006

Cut-off criteria for initial inclusion of inputs and outputs

When conducting an LCA study, it may be required to specify cut-off criteria to be applied to data describing the inputs to, and outputs from, a life cycle stage or process. The reason for doing so is to limit the resources expended in calculating the environmental flows associated with small and insignificant inputs.

The following cut-off criteria were employed.

- Mass: if a material flow comprised less than 1% of the cumulative mass of all the inputs to, or outputs from, a life cycle stage or process, the flow could be excluded, provided its environmental relevance was considered negligible.
- Energy: if an energy flow comprised less than 1% of the cumulative energy of all the inputs to, or outputs from, a life cycle stage or process, the flow could be excluded, provided its environmental relevance was considered negligible.
- Environmental relevance: if a material or energy flow comprised less than 1% of the cumulative material or energy of all the inputs to, or outputs from, a life cycle stage or process, yet was thought potentially to have a significant environmental impact, it was included.
- The sum of the excluded flows did not exceed 5% of mass, energy or environmental relevance.

In practice, all flows for which life cycle inventory data exist were included. For flows where inventory data do not exist, the cut-off criteria, along with expertise as to the environmental relevance of the flow, were used to judge significance and whether additional effort was required to generate new inventory data.

2.2.6 Allocation procedures

The ISO standards on LCA provide a stepwise procedure for the allocation of material and energy flows and environmental emissions when there are interactions between product systems. Preferably, allocation should be avoided, either through first increasing the level of detail, or failing this, through system expansion. Where these methods are not applicable, the ISO standard suggests that allocation be undertaken in a way that reflects the physical relationships between the different products or functions. Allocation based upon mass is a practical interpretation of this and an approach often used in LCA. For some processes, allocation based on mass is not considered appropriate. For these, other relationships (generally economic value) can be used for allocation.

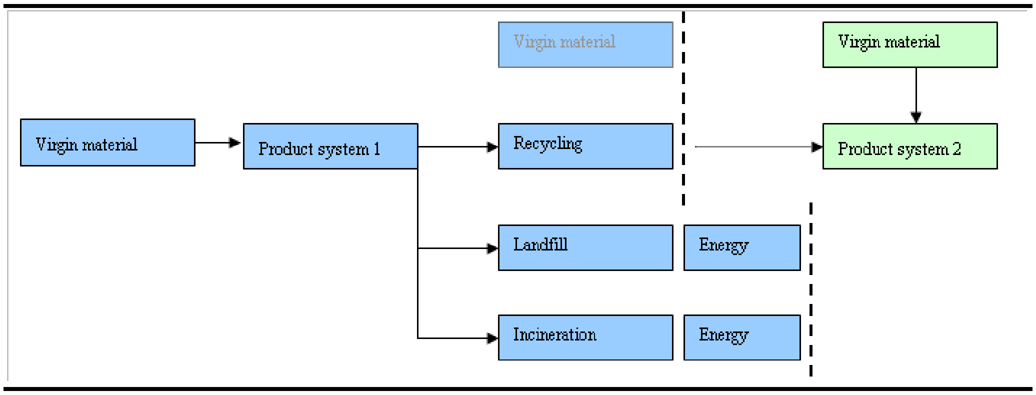
For this study, system expansion into other product systems was not expected to be required, as there is currently no use of recycled materials or recycling at end of life for this product.

Allocation was used for energy and water use data related to Lubrizol manufacturing data (e.g. CPVC compound), as the data were based on site data. Allocation was done using a mass approach (production volumes).

Sensitivity analysis

A sensitivity analysis to consider future recycling rates and its implications was conducted. In order to meet this goal system expansion was used to account for the recycling process burden and to estimate the environmental benefits of recycling through the displacement of virgin material requirements in other product systems.

Figure 2.2 System expansion and allocation principles for two product systems



The environmental burdens of transporting material (including packaging) to the recycling operation are assigned to the product system generating the output (product system 1). The environmental burdens associated with recycling are assigned to product system generating the output (product system 1).

The environmental burdens associated with landfill (including transport) are assigned to the product system generating the output (product system 1). It is assumed that the environmental impacts of the waste management process are not altered by the generation of electricity/heat (i.e., in the case of landfill, it is assumed that operations that do not generate electricity collect and flare landfill gas). As a consequence, electricity/heat generated from these processes is available to other product systems free of burden.

The use of recycled material by product system 1 results in an equivalent saving of virgin material. This 'offset benefit' is assigned to product system 1. In order to ensure a balance of burdens and benefits between the two product systems, it is necessary to model all recycled material inputs to product system 2 as virgin material.

2.2.7 *Assumptions and limitations*

Where specific data were not available and estimates or assumptions were applied, these were clearly described and specified in the report. Where the estimates or assumptions were found to have a significant influence on the overall environmental profile of the different packaging systems, their influence was further investigated in the sensitivity analysis.

The main exclusions in this study are listed below.

- Exclusions are listed in the relevant life cycle section of this *Annex*.
- Capital burdens were excluded from this study.
- Human labor for installation and removal was excluded, but was discussed through a sensitivity analysis.

2.2.8 *Modeling and calculations*

The LCA model was developed in SimaPro 7.1 life cycle assessment software developed by PRé consultants. SimaPro is used extensively within the LCA community and contains a large database of processes (including Ecoinvent 2.0) and all impact assessment methods required to complete this study.

2.2.9 *Inventory results*

Inventory analysis involves data collection and calculation procedures to quantify the relevant inputs and outputs of a product system. For the BlazeMaster® pipe, summary inventory data are included in the technical report.

The summary inventory data include the following:

- raw material use (oil, coal and natural gas);
- CO_2 emissions (fossil and renewable);
- methane emissions (fossil and renewable);
- water use (excluding cooling water, sea water, and hydropower use); and
- cumulative energy demand (renewable and non-renewable).

Water use was included due to environmental and political concerns relating to water use in the USA and globally.

2.2.10 *Impact categories and impact assessment methods considered*

The nature of the fossil based product system means that it will incur burdens across impacts associated with petro chemical product systems. The environmental indicators and impacts listed below cover the main identified and documented issues. The study will not address social impacts, biodiversity or local impacts such as noise.

- Resource depletion (metal and fossil depletion)
- Acidification
- Eutrophication
- Climate change (Global Warming Potential over 100 years [GWP 100])
- Ozone layer depletion
- Human toxicity
- Fresh water ecotoxicity
- Terrestrial ecotoxicity
- Photo-oxidant formation
- Water depletion
- Energy consumption

The impact assessment method used in this study is the problem oriented approach developed by CML (Centre for Environmental Science, Leiden University), updated this year as ReCiPe, and incorporated into the SimaPro LCA software tool.

ReCiPe was developed to provide a single impact assessment method that combines both mid-point and end-point analysis. It is named as such as it is intended to provide a recipe to calculate life cycle impact category indicators. The capitalized letters represent the major contributors to the project, being RIVM and Radboud University, CML, and PRé.

This method was employed because it:

- offers a consistent and scientifically accepted set of characterization methods for the breadth of environmental impacts;
- has a track record of development and use by the LCA community and governments globally;
- is justified by peer reviewed publications and detailed scientific supporting material; and
- conforms with the ISO standards for LCA.

Normalization and weighting of the results was not undertaken in this study.

2.2.11 *Interpretation to be used*

The interpretation phase of the study identifies significant issues based on the results and evaluates these considering completeness, sensitivity, and consistency. Conclusions, limitations and recommendations are then drawn.

The issues considered as part of the interpretation phase include:

- environmental impacts from PVC production;
- impacts of PVC waste in landfill; and
- projected recycling rates.

2.2.12 *Critical review process*

The ISO standards on LCA advocate critical review to facilitate understanding and to enhance the credibility of an LCA. When performing a non-comparative LCA intended to be disclosed to the public or a third party, the standard requires a critical review to be undertaken. In line with the standards, this study will undergo critical review by a single critical reviewer instead of a critical review panel as is defined for a comparative LCA. The reviewers' Critical Review Statement, the commissioners' comments and ERM's responses to the points raised therein, are to be included in the final report.

The purpose of a critical review is to ensure that:

- the methods used to carry out the LCA are consistent with ISO 14040ff;
- the methods used to carry out the LCA are scientifically and technically valid;
- the data used are appropriate and reasonable in relation to the goal of the study;
- the interpretations reflect the limitations identified and the goal of the study; and
- the study report is transparent and consistent.

The critical review will be conducted as an integral review running alongside, and in parallel with, the project management and technical delivery of the LCA. The benefit of this approach is that the critical reviewer's comments and findings are integrated into the scope and delivery as the project proceeds. The key points at which this review will be carried out are as follows.

- Draft Goal and Scope report stage: this review includes checks on the goal and scope of the study, including that the goal of the study is unambiguously stated and that it includes the intended application and audience; that the scope is adequately described with respect to functions of product systems, functional unit, product system and system boundaries to be used, allocation procedures, types of impact and method of impact assessment, data requirements, assumptions and limitations, type of critical review and format for reporting.

- Draft Technical Report stage and the preparation and delivery of a peer review statement: this includes checking that comments raised in the first stage have been incorporated, the format of the report is compliant with ISO 14040 requirements and that the conclusions and interpretation are appropriate in the context of the Goal and Scope of the study.

- Revised Final Draft Report stage: this review is to confirm that the report still conforms to ISO 14040 requirements after any comments have been included by the commissioner and ERM and sign-off on the final report.

Critical reviewer

The critical reviewer is Professor Dr Walter Klöpffer, Editor-in-Chief of the International Journal of Life Cycle Assessment.

2.2.13 Reporting

According to the ISO standards, when results of an LCA are to be communicated to any third party, a third-party report shall be prepared. The third party report shall be made available to any third party to whom the communication is made. The report fulfills the requirements of the ISO standard for a third party report.

3 *LIFE CYCLE INVENTORY (LCI)*

This section contains the LCI descriptions and data used to represent BlazeMaster® in this study. Assumptions, limitations and exclusions are documented throughout. The section is divided as follows:

- *System Overview;*
- *CPVC Compound Production;*
- *Solvent Cement Production (1.2% of Total* Mass) *;*
- *Pipe and Fittings ;*
- *Wholesale;*
- *Installation, Use and Removal; and*
- *End of Life.*

3.1 *SYSTEM OVERVIEW*

Table 3.1 summarizes the main system components by weight and percentage to identify the relative significance of each component. *Figure 2.1* defines the complete system under review in this study.

Table 3.1 Mass of system components

Component	Mass for 304.8 m (1 000 ft) of BlazeMaster® (kg)	Percentage of total mass
CPVC compound (for pipe)	118.87	78.6%
CPVC compound (for fittings)	19.24	12.7%
Solvent cement	1.85	1.2%
Hangers and screws	11.34	7.5%
Total	***151.30***	***100%***

Source: ERM (2009)

3.2 *CPVC COMPOUND PRODUCTION (91.3% OF TOTAL MASS: 78.6% FOR PIPE AND 12.7% FOR FITTINGS)*

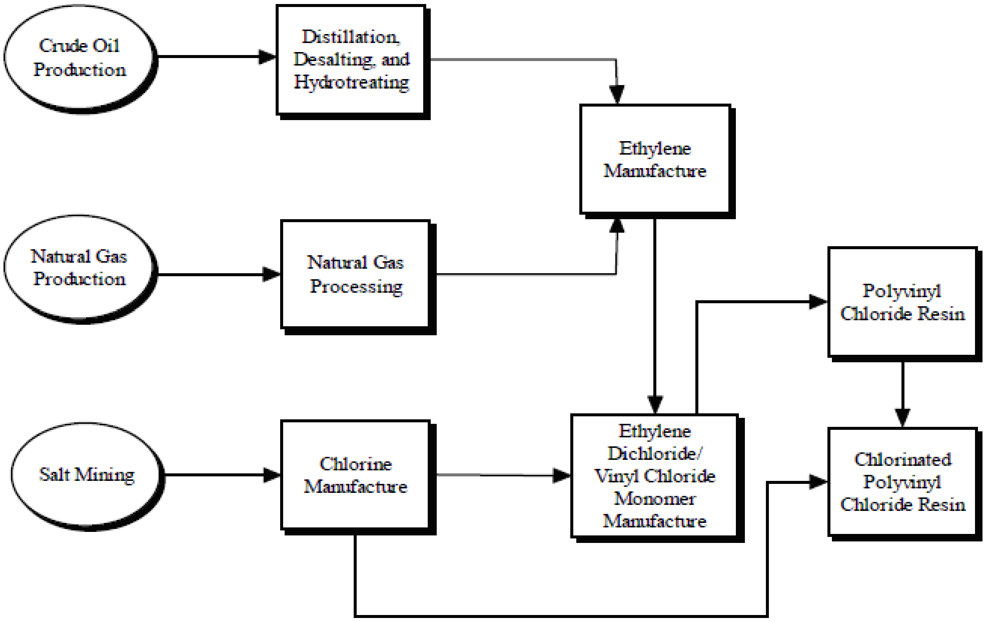
Chlorinated polyvinyl chloride (CPVC) is a thermoplastic produced by chlorination of polyvinyl chloride (PVC) compound. Lubrizol produces two types of CPVC compound at their Louisville, Kentucky facility:

1. CPVC compound for BlazeMaster® pipe; and
2. CPVC compound for BlazeMaster® pipe fittings.

The production processes for each compound are similar. However, the formulations differ slightly.

For each compound, the PVC and chlorine gas are placed in water and exposed to ultraviolet (UV) light. The chlorine replaces labile hydrogen on the PVC backbone. This increases the chlorine content of the material and creates CPVC compound. Afterward, the residual hydrochloric acid (HCl) is stripped from the chlorinated compound and the material is then dried (1).

Figure 3.1 *CPVC compound and pipe production diagram*



Source: Franklin Associates (2008) LCI of the Production of Plastic and Metal Pipes for Use in Three Piping Applications

Next, the CPVC compound is compounded with various additives in an intensive mixer. For the pipe compound, the powder compound is boxed and shipped to Lubrizol's customers who produce the product (i.e., BlazeMaster® pipe). For the fittings compound, the powder compound is then pelletized with a twin screw extruder to produce fused pellets. The pellets are then shipped to the customer (2).

Table 3.2 presents the input and output production data for the BlazeMaster® compounds. These data were provided by Lubrizol.

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(1) From data collection questionnaire completed by Lubrizol for this LCA in December 2009.
(2) From data collection questionnaire completed by Lubrizol for this LCA in December 2009.

Table 3.2 Input/output information to produce one kilogram (1 kg) of CPVC compound

Input/output	**BlazeMaster® pipe compound***	**BlazeMaster® fittings compound***	**Unit**	**Comments**
Material inputs				
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Energy inputs				
CONFIDENTIAL BUSINESS INFORMATION				
Other inputs				
CONFIDENTIAL BUSINESS INFORMATION				
Emissions to air				
CONFIDENTIAL BUSINESS INFORMATION				

Input/output	BlazeMaster® pipe compound*	BlazeMaster® fittings compound*	Unit	Comments
CONFIDENTIAL BUSINESS INFORMATION				
Emissions to water				
CONFIDENTIAL BUSINESS INFORMATION				
Waste to treatment				
CONFIDENTIAL BUSINESS INFORMATION				

3.2.1 Raw material production

This *Section* describes the unit process data for the components used to produce BlazeMaster®. System diagrams and data are provided where available.

PVC

PVC is a thermoplastic and one of the main components used in the production of CPVC. It was assumed that the production process used is suspension polymerization, as more than 90% of the PVC produced in North America is by this method (1). The PVC polymer used by Lubrizol is sourced from two suppliers: one located in Ontario, Canada; and one in Texas. Manufacturing data for PVC polymer were taken from the US Department of Energy (DOE) National Renewable Energy Laboratory (NREL) life cycle database and are detailed in *Table 3.3*.

These data were originally compiled for the Plastic Division of the American Chemistry Council (ACC) revised final report titled *Cradle-to-Gate LCI of Nine Plastic Resins and Two Polyurethane Precursors*, which was produced by Franklin Associates in 2007. Ecoinvent data, with US specific data where available, were used to represent all inputs and outputs to the PVC system.

A process map is depicted in *Figure 3.2* and a detailed description of the data source is provided below.

Table 3.3 Input/output information to produce one kilogram (1 kg) of PVC compound

Input/output	Quantity	Unit
Material and fuel inputs		
Electricity, medium voltage, at grid/US SNI	0.164	kWh
Natural gas, burned in gas turbine/GLO SNI	0.612	kWh
Transport, freight, rail, diesel/US SNI	0.28	tkm
Electricity, at cogen 6400kWth, wood, allocation energy/CH SNI	0.091	kWh
Ethylene dichloride-vinyl chloride monomer production (cradle to gate) - US NREL data	1	kg
Transport, crude oil pipeline, onshore/RER SNI	0.0039	kg
Emissions to air		
Methane, trichlorofluoro-, CFC-11	0.000001	kg
Chlorine	0.00001	kg
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	1.57E-11	kg

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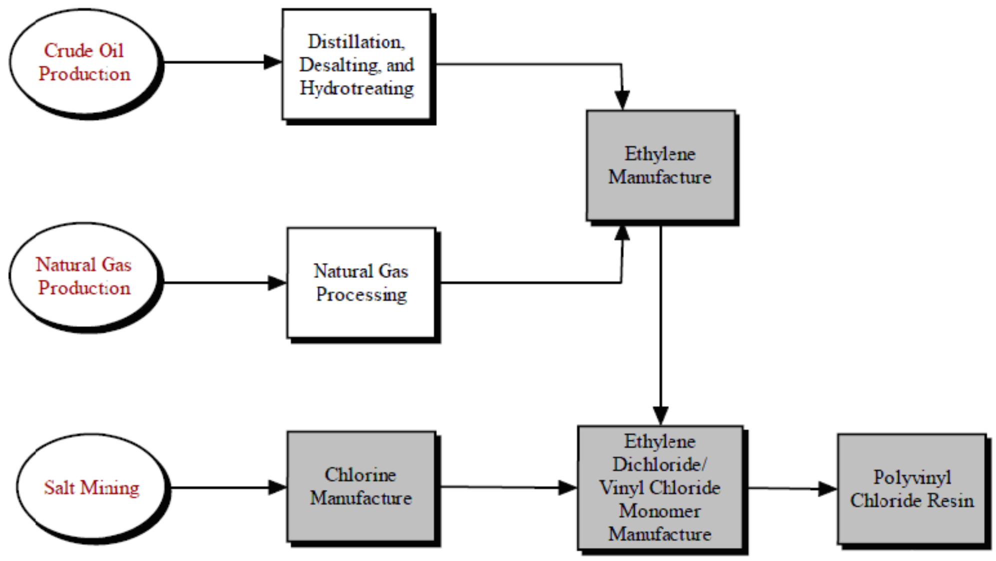
(1) Franklin Associates (2008) *LCI of the Production of Plastic and Metal Pipes for Use in Three Piping Applications*.

Input/output	Quantity	Unit
Ethene, chloro-	0.000039	kg
Hydrogen chloride	1E-07	kg
Organic substances, unspecified	0.000039	kg
Particulates, unspecified	0.000087	kg
Emissions to water		
Ammonia	0.000001	kg
BOD5, Biological Oxygen Demand	0.000012	kg
Chromium, ion	1E-07	kg
COD, Chemical Oxygen Demand	0.000068	kg
Cyanide	1E-09	kg
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	5.83E-11	kg
Nitrogen, total	0.00001	kg
Oils, unspecified	0.000001	kg
Phenols, unspecified	9.9E-08	kg
Suspended solids, unspecified	0.00016	kg
Zinc	1E-07	kg
Waste to treatment		
Disposal, polypropylene, 15.9% water, to municipal incineration/CH SNI	5.2E-07	kg
Disposal, polypropylene, 15.9% water, to sanitary landfill/CH SNI	0.0011	kg

Source: NREL adapted data

*Figure 3.2 PVC resin production diagram**



Source: Franklin Associates (2007) Cradle-to-Gate LCI of Nine Plastic Resins and Two Polyurethane Precursors

** Shaded boxes represent partial or complete data provided by manufacturers specifically for this analysis.*

PVC polymer production description (1)

In the suspension process, vinyl chloride monomer (VCM) and initiators are mixed with water and kept in the form of aqueous droplets by agitation and suspension stabilizers. The polymerization generally is carried out in a nitrogen atmosphere in large agitated reactors. The reaction time is typically about 12 hours, and conversion of VCM approaches 90%. After polymerization, the unreacted monomer is removed and recycled. The polymer is blended with additives and modifiers and centrifuged to remove water. The PVC polymer resin is then dried and packaged for shipment.

The data for the production of PVC were sourced from three leading producers (three plants) in North America by Franklin Associates under contract to Plastics Division of the ACC.

All data submitted for PVC range from 2003-2004 and represent US production.

As of 2003, there were 12 PVC producers and 25 PVC plants in the US. While data were collected from a small sample of plants, the PVC producers who provided data for this module verified that the characteristics of their plants are

(1) http://www.nrel.gov/lci/database/pdf/MR_PolyvinylChloride-UnitProcess.pdf.

representative of a majority of North American PVC suspension technology production. The average dataset was reviewed and accepted by all PVC data providers.

Chlorine

A confidentiality agreement was signed with Lubrizol's chlorine producer, PPG, to provide life cycle manufacturing data for chlorine production. The chlorine producer applied a mass allocation between the process outputs, chlorine and caustic soda.

Chlorine production is primarily achieved through diaphragm process with a small proportion produced from mercury cell process. The mercury cell process is being phased out by the supplier. The small amount of mercury emission to air from this supplier is an assumed consequence of the mercury cell process.

A review of the data placed it within the process data ranges featuring in published chorine life cycle inventories (from Ecoinvent LCI database).

Water

Water is used for resin chlorination and is combined with chlorine gas. Water was approximated as water, de-ionized, at plant/CH SNI from the Ecoinvent LCI database.

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Table 3.4

Table 3.5

CONFIDENTIAL BUSINESS INFORMATION

Table 3.6

Table 3.7

CONFIDENTIAL BUSINESS INFORMATION

Table 3.8

Electricity inputs for chemical production were estimated based upon average energy consumption used during average inorganic chemical production (3.64 MJ/kg for inorganic chemical production from the Ecoinvent LCI database). A kilogram of the Ecoinvent 2.0 “chemicals, inorganic, at plant/GLO” (1) was analyzed and the energy figure taken from these results. The assumption of 100% electricity can be a considered a worse case.

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(1) Althaus H, et al (2007) Life Cycle Inventories of Chemicals. Final report Ecoinvent data v2.0. Volume: 8. Swiss Centre for LCI, Empa - TSL. Dübendorf, CH.

Orange pigment

Fire sprinkler pipes are required to be a certain color (orange) to distinguish them from pipes used for plumbing. The orange pigment used in the CPVC compound production is an organic compound and accounts for less than 0.01% of the total mass. From the MSDS the orange pigment is identified as an organic pigment with an LD50 of >2000mg/kg (rat) and no hazardous ingredients under 29 CFR 1920, 1200 and Title III of SARA. Therefore its production was excluded from this study.

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3.2.2 Raw material transport

The production location of all raw materials was provided by Lubrizol and is summarized in *Table 3.9*. Distances were also provided for domestically sourced (i.e., within the continental United States (US)) raw materials. Ecoinvent data for average fleet trucks (various sizes) and US diesel freight rail were assumed for road and rail transport, respectively.

Transport distances were not provided for internationally sourced raw materials as the shipping and receiving ports are not known by Lubrizol. An Ecoinvent process for a transoceanic freight ship was assumed to account for the sea journey, with distances calculated using internet mapping systems.

It was assumed that European sourced products are shipped from the closest port city to the production site to New York, which is the largest port on the eastern coast of the US. An additional 1 234 km (767 mi) of road transport was assumed to account for the distance from the New York port to the Louisville manufacturing site.

Additional road transport distances were added for the orange pigment and lubricant as the manufacturing locations are not in port cities. Nearby port cities of Barcelona and Amsterdam were assumed for each, respectively. Shipments from China were assumed to arrive via Los Angeles.

Table 3.9 Raw material production location, transport methods and transport distances

Material inputs	Source location	Transport method	Distance (km)*

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3.2.3 *Raw material packaging*

The packaging details for the raw materials were provided by Lubrizol and are summarized in *Table 3.10.* Bulk reusable transit packaging such as shipping containers was assumed to have negligible impact and was therefore excluded.

The polypropylene packaging was modeled using Ecoinvent data for polypropylene granulate and an extrusion process. The cardboard and paper bags were modeled using Ecoinvent data for corrugated cardboard and Kraft paper, respectively. All packaging was taken to be disposed of in landfill, as per the information collected from Lubrizol.

Wooden skids or pallets that are used for the minor ingredients were excluded due to the negligible impact associated with their use. Pallets are not used for the most significant (by mass) ingredients, including PVC, chlorine or water.

Table 3.10 Raw material packaging

Material input	Packaging material	Quantity (kg)	End of life	Modeled assumptions/data source

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3.2.4 *Raw material production and packaging waste management*

Ecoinvent data for disposal was used to represent industrial landfill (inert landfill) and sewer sludge (sewer sludge to wastewater treatment). The benefits associated with the beneficial use of the lime slurry and recycled packaging were considered to be outside the boundaries of this project. However, this also takes into account the avoided burdens should this material have gone to landfill. Transport to disposal facilities was included in this study, with an assumed 50 km distance by average fleet truck >28 T/CH from the Ecoinvent LCI database.

3.2.5 *Compound transport to manufacture*

Transport from the compound production plant in Louisville, Kentucky to the [manufacturing facility] is approximately [X] km. A 20-28 metric ton fleet average truck was assumed for road transport.

3.3 *Solvent Cement Production (1.2% of Total Mass)*

Solvent cement is used for joining BlazeMaster® pipes during installation. Lubrizol calculated that 1.89 liters (4 US pints) of cement are used to install 304.8 m (1 000 ft) of pipe.

The life cycle data used to model this material are detailed below.

3.3.1 *Solvent cement raw materials*

The material input data for the production of solvent cement were estimated from composition data and are presented in *Table 3.11*.

Table 3.11 *Solvent cement raw materials (to produce 0.473 l (1 US pint))*

Material input	Quantity	Units	Comments
Acetone, liquid, at plant/RER SNI	0.0464	kg	5% to 15% acetone; 10% assumed
Tetrahydrofuran, at plant/RER SNI	0.218	kg	40% to 55% tetrahydrofuran; 47% assumed
Methyl ethyl ketone, at plant/RER SNI	0.0464	kg	5% to 15% methyl ethyl ketone; 10% assumed
Cyclohexanone, at plant/RER SNI	0.0464	kg	5% to 15% cyclohexanone; 10% assumed
CPVC compound	0.102	kg	15% to 30% CPVC compound; 22% assumed; this was modeled using Lubrizol data for the BlazeMaster® pipe compound
Silica sand	0.00464	kg	1% to 5% amorphous fumed silica; silica sand assumed at 1%

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VOC emissions have been estimated based on 100% release of acetone. A vapor pressure comparison was used to determine the release rate of the other VOCs: tetrahydrofuran (100%), methyl ethyl ketone (100%) and cyclohexanone (2%).

A 500 km distance has been assumed for the transport of the raw materials to the unknown manufacturing site. A 20-28 metric ton fleet average truck was assumed for road transport.

It was assumed that no packaging was used and that there was no waste of raw materials.

3.3.2 *Solvent cement production*

The emissions and energy consumption data for solvent cement formulation were estimated using data for a mixing process for alkyd paint (white, 60% in solvent at plant, Ecoinvent data). This process only includes energy consumption and emissions from alkyd paint production. It was assumed that this is predominantly mixing and this would be similar to mixing the raw materials for solvent cement.

3.3.3 *Solvent cement packaging*

It was assumed that packaged solvent cement has a mass of 6.7 kg (14.7 lbs) per case of 12 individual pints (1). There is approximately 0.4635 kg of cement in each can; the difference was assumed to be the can. Based on cements on the market, it was assumed that the can in manufactured from aluminum. Ecoinvent data for an aluminum production mix (at plant) with the addition of a section bar extrusion process for aluminum was used to represent the solvent cement packaging.

3.3.4 *Solvent cement transport to wholesale*

A 500 km distance was assumed for the transport of the solvent cement from the unknown manufacturing site to the wholesaler in Grand Rapids, Michigan. A 20-28 metric ton fleet average truck was assumed for road transport.

3.4 *HANGER AND SCREWS PRODUCTION (7.5% OF TOTAL MASS)*

Hangers are used to support the pipe once installed. Lubrizol provided data that noted 11.3 kg (25 lbs) of steel hangers are used to install 304.8 m (1 000 ft) of pipe. This is equivalent to 250 individual hangers.

In addition, two stainless steel screws are required for each hanger (i.e., 500 screws total). An actual screw was weighed by ERM using digital scales to determine the mass; this was calculated to be 0.00155 kg (0.0034 lbs) (2).

It was assumed that the hangers and screws are manufactured in China and shipped to Los Angeles, and then transported by road to the wholesale location in Grand Rapids. Three transport distances were estimated by ERM:

1. 500 km by road in China for raw material transport to manufacture;
2. 11 646 km by transoceanic freight ship from Hong Kong to Los Angeles; and
3. 2 978 km from Los Angeles to Grand Rapids.

3.4.1 *Hanger and screws raw materials*

Modified Ecoinvent data for cast iron production were used to represent the raw materials for the hangers. The data were adapted to account for a Chinese-based electricity mix.

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(1) http://www.herchem.com/specs/pipecement.pdf

(2) Based on ERM measurement of the mass of a 0.00155 kg Phillips screw; 3.175 mm (1.25 in) long with a head diameter equivalent to 8mm.

Ecoinvent data for the production of low alloyed steel, at plant, were used to represent the screws. The data were not adapted to account for a Chinese based electricity mix as the screws are a very small proportion of the total mass.

A 500 km distance was assumed for the transport of the raw materials to the unknown manufacturing site for both the brackets and screws. A 20-28 metric ton fleet average truck was assumed for road transport.

It was assumed that no packaging was used, and that there was no waste of raw materials.

3.4.2 Hanger and screws production

The hangers were modeled as a steel sheet rolling process using modified Ecoinvent data. The data were adapted to account for a Chinese based electricity mix.

The screws have been modeled as an average wire drawing process using modified Ecoinvent data. The data has been adapted to account for a Chinese based electricity mix.

3.4.3 Hanger and screws packaging

It was assumed that the hangers and brackets are purchased in bulk and therefore any packaging is insignificant in the context of hangers and screws and the considered product system.

3.4.4 Hanger and screws transport to wholesale

As noted above, a distance of 11 646 km by transoceanic freight ship from Hong Kong to Los Angeles and 3 385 km from Los Angeles to Grand Rapids was assumed. A 20-28 metric ton fleet average truck was assumed for road transport using Ecoinvent LCI data.

3.5 PIPE AND FITTINGS MANUFACTURE

Manufacturing data were collected from

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To produce 304.8 m (1 000 ft) of BlazeMaster®, 118.87 kg (262 lbs) of CPVC compound are needed for the pipe and 19.24 kg (42.42 lbs) (i.e., 260 fittings) of compound are needed for the fittings.

3.5.1 *Pipe manufacture*

Extrusion is used to produce plastic pipes. This process involves bulk feeding the compound powder into twin screw extruders where it is melted and forced through a die. The extrudate from the di.e., is then formed and cooled. It goes through a control/monitor process during processing and is packaged at the end.

Data collected for the extrusion process are summarized below. Wastage and emissions were reported as zero. A wastewater emission was added to mass balance the incoming water.

Table 3.12 Input/output information to produce 304.8 m (1 000 ft) of BlazeMaster®

Input/output	**Quantity**	**Unit**
Electricity	86	kWh
Water	1 084	liters

Source: [Facility operator] (2009)

[Facility operator] calculated the average maximum electrical draw across all extruders and multiplied this by the average number of hours required to produce 304.8 m (1 000 ft) of pipe. The water is used for cooling processes.

Packaging to wholesale

It was estimated by [the facility operator] that small quantities of BlazeMaster® pipes are bundled together in plastic sleeving weighing between 18.1 – 29.5 kg (40 - 65 lbs). Generally, 21 bundles are placed in reusable wooden frames (lifts) for shipping. It was estimated by [the manufacturer] that an average of 1.65 kg of plastic film are used for every 304.8 m (1 000 ft) of pipe. Ecoinvent data for low-density polyethylene (LDPE) plastic film was used to represent this information. Due to their reuse the wooden frames (i.e., pallets) have been excluded from this study.

It is assumed that the plastic packaging passes through the wholesaler without being removed and is sent to the installation site. Regardless of end location for the packaging, it was assumed to be sent to landfill and not recycled. Ecoinvent data for polyethylene to sanitary landfill was used to represent these data.

Transport to wholesale

Transport from the [manufacturing facility] to a wholesaler in Grand Rapids, Michigan has been estimated at approximately [X] km. A 20-28 metric ton fleet average truck has been assumed for road transport.

3.5.2 *Fittings manufacture*

To produce the BlazeMaster® fittings, the CPVC compound pellets are first bulk-fed into molding machines where they are formed, cooled, ejected and in some cases inspected, degated and bagged as a finished good.

As with the pipe manufacture, data for the manufacturing were collected from the facility operator. The data collected are summarized below.

*Table 3.13 Input/output information to produce 260 fittings**

Input/output	**Quantity**	**Unit**
Electricity	178.88	kWh

Source: [Facility operator] (2009)

** This is equivalent to 178.88 kWh for 260 fittings, the amount needed to install 304.8 m (1 000 ft) of BlazeMaster®. Data were provided as 688 kWh for 1 000 fittings.*

[The facility operator] calculated the average maximum electrical draw across all molding machines and multiplied this by the average number of hours required to produce 1 000 fittings.

Packaging to wholesale

Small / predetermined quantities of fittings are bagged in plastic bags and then placed into either a 30.48 x 30.48 x 30.48 cm (12 x 12 x 12 in) box or a 30.48 x 30.48 x 15.24 cm (12 x 12 x 6 in) box in preparation for shipping to customers (i.e., wholesalers). The number of bags per box is determined by the size of the part.

[The facility operator] estimated that 3.67 kg of corrugated cardboard and 0.77 kg of LDPE packaging film are used to transport 1 000 fittings. Ecoinvent data was used to represent these processes.

It was assumed that the packaging passes through the wholesaler without being removed and is sent to the installation site. Regardless of end location for the packaging, it was assumed to be sent to landfill and not recycled. Ecoinvent data for packaging cardboard and polyethylene to sanitary landfill were used to represent this information.

Transport to wholesale

Transport from the [manufacturing facility] to a wholesaler in Grand Rapids, Michigan was estimated at approximately [X] km. A 20-28 metric ton fleet average truck was assumed for road transport.

3.6 *WHOLESALE*

After the BlazeMaster® pipes are manufactured; they are shipped to wholesale retail locations around the US. Typically, there is one or many wholesale stores located in each major commercial center. For the purposes of this study, the wholesale center (and installation site) was chosen by Lubrizol to be Grand Rapids, Michigan, as this represents a typical US installation scenario where climatic conditions do not favor one type of fire sprinkler systems.

A wholesale location is typically a large retail warehouse facility (1). For the purposes of this study, an electricity input was included to represent the time in the wholesale location.

3.6.1 *BlazeMaster® pipes*

It was assumed that non-refrigerated floor space takes up 5.3 kWh per sq ft (2) and that 12 pipes side by side is approximately 30.48 cm (1 ft), which is based on 12 pipes x 2.54 cm/pipe (1 in). It was assumed that the pipes are stacked up to one meter (3.28 ft) high in bulk, which is approximately 36 layers of pipes. The energy was use was based on a calculation of 1000 ft / (12 x 36 pipes) at 5.3 kWh per sq ft.

12.3 kWh of medium voltage grid electricity for the US was used to represent the electricity input at the wholesale location for 304.8 m (1 000 ft) of pipe.

3.6.2 *BlazeMaster® fittings*

It was assumed that 1 000 fittings can be stored in 1 sq ft of space. 5.3 kWh of medium voltage grid electricity for the US was used to represent the electricity input at the wholesale location for 1 000 fittings.

3.6.3 *Solvent cement*

Due to the minor quantity of solvent cement used in this study, the electricity associated with a warehouse was considered negligible and was excluded from this study.

3.6.4 *Hangers and screws*

Due to the minor quantities of hangers and screws in this study, the electricity associated with warehousing was ignored as it was considered to be insignificant.

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(1) Source: Conversation with Lubrizol (2009)

(2) http://www.eia.doe.gov/emeu/cbecs/pba99/warehouse/warehouseconstable.html

3.6.5 *Transport to installation*

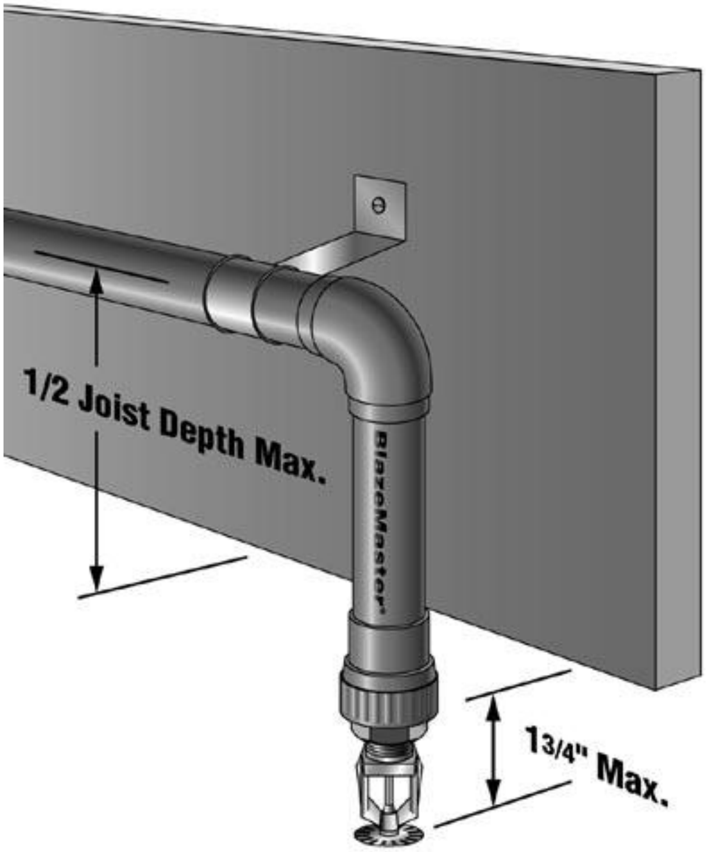
A distance of 100 km on a >28 metric ton fleet average truck was assumed for road transport between the wholesaler and installation site for all materials. No additional transit packaging was assumed for this transport step.

3.7 *INSTALLATION, USE AND REMOVAL*

For this study, it was assumed that BlazeMaster® pipes are installed in a residential high rise building on a smooth, flat, horizontal ceiling as per the BlazeMaster® *Installation and Specification Manual*.

A schematic of an installed pipe is included below in *Figure 3.3*.

Figure 3.3 Figure of hangers supporting a branch of pipe



Source: BlazeMaster® Installation and Specification Manual, p 9
Note: The sprinkler head is outside the scope of this study

3.7.1 Installation

No consumption impacts were associated with the installation of BlazeMaster® as the procedure is completely manual, i.e., without the use of electrical equipment. A sensitivity analysis was carried out to estimate the impact associated with replacing manual labor for a mechanized installation process (refer to *Section 6.1*). The use of ratchets, saws, rags and solvent cement applicators was excluded from this study. A drill is used to install the hanger screws. However, the energy (i.e., battery power) used to operate a hand drill was excluded on an immateriality basis.

The installation procedure summarized below was taken directly from the BlazeMaster® *Installation and Specification Manual*.

It was assumed that 5% of pipe materials are wasted during the installation process from cutting (1). It was assumed that no other materials are wasted.

Handling and storage

BlazeMaster® pipes and fittings are made from a tough, corrosion resistant material, but do not have the mechanical strength of steel. Reasonable care must be exercised in handling.

BlazeMaster® pipe must be covered with a non-transparent material when stored out of doors for extended periods of time. Brief exposure to direct sunlight on the job site may result in color fade but will not affect physical properties. BlazeMaster® fittings should be stored in their original container/packaging to keep them free from dirt and reduce the possibility of damage.

It was assumed that the pipe is not stored outside.

Cutting

BlazeMaster® pipe can be easily cut with a ratchet cutter, a wheel-type plastic tubing cutter, a power saw or a fine toothed saw (refer to *Figure 3.4*). To ensure the pipe is cut square, a miter box is recommended when using a saw. A square cut provides the surface of the pipe with maximum bonding area.
Capital burdens associated with the ratchet/saw and miter were excluded from the study.

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(1) Based on conversation with Lubrizol (2009)

Figure 3.4 ***Cutting***

Source: BlazeMaster® Installation and Specification Manual, p 20

Deburring

Burrs and filings can prevent proper contact between pipe and fitting during assembly, and must be removed from the outside and the inside of the pipe. A chamfering tool (refer to *Figure 3.5*) or a file is suitable for this purpose. A slight bevel is placed at the end of the pipe to ease entry of the pipe into the socket and minimize the chances of wiping solvent cement from the fitting during insertion.

Capital burdens associated with the chamfering tool/file were excluded from the study.

Figure 3.5 ***Deburring***

Source: BlazeMaster® Installation and Specification Manual, p 20

Fitting preparation

A clean, dry rag is used to wipe loose dirt and moisture from the fitting socket and pipe end. Moisture can slow the cure time and, at this stage of assembly, excessive water can reduce joint strength.

Capital burdens associated with rags were excluded from the study.

Solvent cement application

Cement is applied (worked into pipe) with an applicator half the nominal size of the pipe diameter. A heavy, even coat of cement is applied to the outside pipe end and a medium coat to the fitting socket.

A VOC emission of 490 g/litre has been modeled to include the impact of VOC emission during installation and use. This date is from the BlazeMaster® TFP-401 One Step Solvent Cement MSDS, which is based on the SCAQMD (South Coast Air Quality Management District) Test Method 316A.

Figure 3.6 Solvent cement application

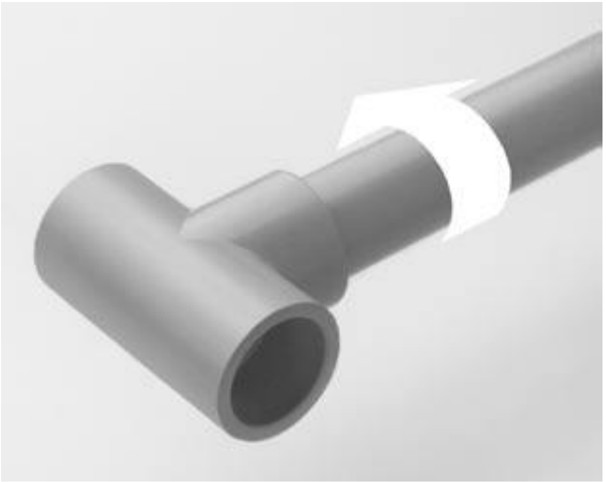
Source: BlazeMaster® Installation and Specification Manual, p 21

Capital burdens associated with the applicator were excluded from the study.

Assembly

After applying the solvent cement, the pipe is immediately inserted into the fitting socket, while rotating the pipe one-quarter turn (refer to *Figure 3.7*). The assembly is held for 10 to 15 seconds to ensure initial bonding. The pipes are left to set, the time being a function of pipe size, temperature, relative humidity, and tightness of fit.

Figure 3.7 Assembly



Source: BlazeMaster® Installation and Specification Manual, p 21

3.7.2 *Maintenance and repair*

No impact was associated with maintenance of BlazeMaster® as, in a typical scenario, no maintenance is required over the lifetime. There is no need to clean or flush the BlazeMaster® system. Should maintenance be required due to overall structural changes etc, a manual cut-in procedure is used.

3.7.3 *Use*

The use phase of BlazeMaster® ® is potentially quite long, Lubrizol suggest a useful life of 50 years. In practice, its useful life is likely to be associated with the life of the building. This phase could theoretically include periodical maintenance and/or repair. However, because maintenance is not required under normal operating conditions, this was excluded from the study. It was assumed that the BlazeMaster® system is not used or damaged during use (i.e., an actual fire).

No emissions from installed piping are anticipated. This assumption is in line with the European Commission LCA on PVC (1).

Should maintenance be required due to overall structural changes etc., a manual cut-in procedure is used. No additional significant impacts were found to occur during the use phase.

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(1) European Commission (2004) *Life Cycle Assessment of PVC and of principal competing materials* Section 4.3.2 Use phase – Pipes.

3.7.4 *Removal*

Similar to installation, all removal is done manually and therefore does not have an associated environmental impact. The impact of replacing manual labor with a mechanized process was addressed through a sensitivity analysis, as noted in *Section 6.1*.

3.7.5 *Packaging to end of life*

It was assumed that no packaging is used during this life cycle stage.

3.7.6 *Transport to end of life*

A distance of 50 km on a >28 metric ton fleet average truck was assumed for road transport between the wholesaler and installation site for all materials.

3.8 *END OF LIFE*

The majority of construction waste in Michigan is disposed of in landfill. Provided that landfills are operated appropriately and responsibly, in accordance with present technical regulations, landfilling is an acceptable intermediate disposal option for products containing PVC. However, because of the long life of BlazeMaster® in comparison to the time it has been commercially available, landfill disposal is likely to be reduced in favor of waste prevention and recovery strategies. Alternate disposal routes were appraised in the sensitivity analysis.

No primary data were sourced describing the performance of CPVC disposed to landfill. Secondary LCI data for disposal of PVC to landfill were sourced from Ecoinvent and are presented below in *Table 3.14*. Ecoinvent based the PVC waste composition on various literature sources (1) and data gaps were filled with data from unspecified average plastics from the same literature sources. The compositions were then normalized to 100%. Ecoinvent estimates 1% degradation for PVC over 100 years and all degradability rates are assumed to be homogeneous.

*Table 3.14 Summary of Ecoinvent data for PVC to landfill**

Input/output	Amount	Unit	Percent of total
Materials/fuels			
Cement, unspecified, at plant/CH U	2.45E-07	kg	81%

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(1) Literature sources used by Ecoinvent: Barrage et al. 1995, Baumann et al. 1993, Bildingmaier 1990, Bilitewski et al. 1991, Brahms et al. 1989, BUWAL 1995b, Domalski et al. 1987, Feess-Dörr et al. 1991, Frankenhäuser et al. 1995, Franssen et al. 1990, Grünewald et al. 1988, Haber et al. 1990, Hamm et al. 1986, IFEU 1991, IFEU 1992, Kaiser 1975, Keilen et al. 1997, Knezevic 1998, Mark et al. 1994a, Mark et al 1994b, Mark et al. 1995, Maystre et al. 1994, Paterna 1995, Rasp 1988, Salami et al. 1992, Stumpf 1994, Thalmann et al. 1982, Tillman 1991, Tuminski 1998, Wünschmann et al. 1995.

Input/output	Amount	Unit	Percent of total
Ammonia, liquid, at regional storehouse/CH U	3.71E-08	kg	12%
Iron (III) chloride, 40% in H2O, at plant/CH U	9.79E-09	kg	3%
Electricity, low voltage, at grid/CH U	0.00027	kWh	~100%
Natural gas/fuel	0.000093	MJ	~100%
Electricity/heat			
Sewer grid, class 3/CH/I U	5.45E-10	km	~100%
Electricity from waste, at municipal waste incineration plant/CH U	0.000012	kWh	~100%
Heat from waste, at municipal waste incineration plant/CH U	0.000069	MJ	~100%
Emissions to air			
Carbon dioxide, fossil	0.011	kg	83%
Methane, fossil	0.0017	kg	13%
Emissions to water			
Chloride	0.46	kg	54%
COD, Chemical Oxygen Demand	0.12	kg	14%
TOC, Total Organic Carbon	0.11	kg	13%
DOC, Dissolved Organic Carbon	0.11	kg	13%
Emissions to soil			
Heat, waste	0.12	MJ	~100%
Waste to treatment			
Process-specific burdens, sanitary landfill/CH U	1	kg	~100%

** This summary provides the most significant inputs and outputs to the process.*

The European Commission PVC LCA analyzed the long-term behavior of PVC in landfills. Although PVC was considered by the authors to be subject to leaching and degradation, it was noted that degradation of the PVC polymer was not observed, and the vinyl chloride in landfill gas does not originate from PVC products, but from volatile chlorinated carbons, such as perchloroethylene. In addition, it was noted that the concentrations of plasticizers in the leachate are not correlated with losses (1). However, other research would suggest circumstantial evidence as to the degradation of PVC due to the unaccounted levels of vinyl chloride in landfill emissions.

The report stated that the contribution of PVC products to the inventory of heavy metals in municipal solid waste is low. PVC products do constitute major sources of phthalic and organotin compounds, but they are not the sole source of these. The study concluded that there was no immediate need for action with respect to the target substances found in landfill leachate (2).

(1) European Commission (2004) *Life Cycle Assessment of PVC and of principal competing materials* Section 4.4.2 Landfill.

(2) European Commission (2004) *Life Cycle Assessment of PVC and of principal competing materials* Section 4.4.2 Landfill.

For the purpose of this study, it was assumed that all waste is sent to landfill. The direct processes are noted below in *Table 3.15*.

Table 3.15 ***End of life modeling assumptions***

Waste material	Modeled assumptions/data source
BlazeMaster® pipe	Disposal, polyvinylchloride, 0.2% water, to sanitary landfill/CH SNI
BlazeMaster® fittings	Disposal, polyvinylchloride, 0.2% water, to sanitary landfill/CH SNI
Brackets and screws	Disposal, steel, 0%, to inert material landfill/CH SNI
Solvent cement	Disposal, polyvinylchloride, 0.2% water, to sanitary landfill/CH SNI*

** The solvent cement was modeled as PVC to landfill as its main ingredient is CPVC and this represents a worst case scenario.*

Legend: CH = Swiss process; SNI = infrastructure is excluded

3.8.1 End of life sensitivity

A new recycling process was created to include the recycling benefit and costs that are allocated to the production of the recycled plastic. To include this benefit and cost, the following data were included: polyethylene; HDPE, granulate (0.4kg); polyvinylchloride (0.15kg); polyethylene terephtalate (0.4kg) was used as avoided product; and 0.6 kWh electricity medium voltage was used as input from technosphere. These are estimated values only.

3.9 DATA COVERAGE AND QUALITY

To assess the overall quality of the data collected for this study, key quality parameters were assessed. These are summarized in *Table 3.16* according to:

- dataset and percentage of total mass;
- source;
- time period;
- geography;
- technology;
- representativeness; and
- precision.

Table 3.16 Data quality

Dataset	Percentage of total mass	Source	Time period	Geography	Technology	Representativeness	Precision
CPVC compound (for pipe)	78.6%	Lubrizol	2009	US	Best practice; process specific	Exact	Measured
CPVC compound (for fittings)	12.7%	Lubrizol	2009	US	Best practice; process specific	Exact	Measured
Pipe manufacture	n/a	[mfr]	2009	US	Above industry standard; process specific	Exact	Measured
Fittings manufacture	n/a	[mfr]	2009	US	Above industry standard; process specific	Exact	Measured
Hangers and screws	7.5%	Ecoinvent	2007	Ecoinvent data adapted for Chinese production and distribution to US	Unspecified	Modified Ecoinvent process	Not specified
Solvent cement	1.2%	Ecoinvent	2007	European	Unspecified	Modified Ecoinvent process	Not specified

4 SUMMARY LIFE CYCLE INVENTORY RESULTS

The inventory data analyzed in this study include:

- raw material use (oil, natural gas and coal);
- CO_2 emissions (fossil and renewable);
- methane emissions (fossil and renewable);
- water use (excluding cooling water, sea water, and hydropower use); and
- cumulative energy demand (renewable and non-renewable).

Table 4.1 and *Table 4.2* present the life cycle inventory results by percentage and absolute value (1), respectively.

The key findings are summarized below.

- The production of the raw materials represents the majority of the inventory, between 59-88%. The production of the PVC granulate is the raw material with the most significant impact on the inventory flows.
- Manufacturing is the second most significant life cycle stage, contributing to the inventory burdens, due to the electricity that is used in this stage.
- The remaining life cycle stages have a less significant impact on the inventory flows.
- The slightly high methane contribution from packaging is a direct result of the cardboard packaging going to landfill.

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(1) These data are rounded to three significant figures.

Table 4.1 Cradle to grave inventory for 304.8 m (1 000 ft) of BlazeMaster® by life cycle stage (%)

	Unit	**Total**	**Raw material production**	**Manufacturing**	**Wholesale/ distribution**	**Installation**	**Use**	**Removal**	**Disposal**	**Transport**	**Packaging**
Oil	kg oil	100%	83%	4%	0%	0%	0%	0%	0%	11%	2%
Natural gas	m^3 gas	100%	86%	12%	1%	0%	0%	0%	0%	1%	2%
Coal	kg coal	100%	58%	39%	2%	0%	0%	0%	0%	0%	1%
Carbon dioxide (fossil)	kg CO_2	100%	67%	26%	1%	0%	0%	0%	0%	4%	1%
Carbon dioxide (biogenic)	kg CO_2	100%	88%	9%	0%	0%	0%	0%	0%	0%	3%
Methane (fossil)	kg CH_4	100%	68%	17%	1%	0%	0%	0%	10%	1%	2%
Methane (biogenic)	kg CH_4	100%	87%	1%	0%	0%	0%	0%	0%	0%	12%
Water depletion	m^3	100%	76%	23%	0%	0%	0%	0%	0%	0%	1%
Energy use (non-renewable)	MJ	100%	72%	22%	1%	0%	0%	0%	0%	3%	2%
Energy use (renewable)	MJ	100%	79%	17%	1%	0%	0%	0%	0%	0%	4%

Table 4.2 Cradle to grave inventory for 304.8 m (1 000 ft) of BlazeMaster® by life cycle stage

	Unit	**Total**	**Raw material production**	**Manufacturing**	**Wholesale/ distribution**	**Installation**	**Use**	**Removal**	**Disposal**	**Transport**	**Packaging**
Oil	kg oil	88.7	73.3	3.56	0.178	0.00843	0	0	0.188	9.38	2.09
Natural gas	m^3 gas	125	107	15.5	0.796	0.000986	0	0	0.012	0.652	2.06
Coal	kg coal	240	139	93.3	4.81	0.00113	0	0	0.0186	0.225	1.82
Carbon dioxide (fossil)	kg CO_2	767	516	199	10.2	0.0976	0	0	2.22	30.9	8.04
Carbon dioxide (biogenic)	kg CO_2	38.8	34	3.48	0.171	0.000444	0	0	0.00916	0.0118	1.09
Methane (fossil)	kg CH_4	2.26	1.53	0.387	0.0191	0.0101	0	0	0.237	0.0304	0.0463
Methane (biogenic)	kg CH_4	0.435	0.379	0.00367	0.000147	8.99E-08	0	0	0.00000149	0.0000117	0.0521
Water depletion	m^3	8.14	6.16	1.87	0.0294	0.000118	0	0	0.00161	0.0291	0.046
Energy use (non-renewable)	MJ	15600	11300	3370	174	0.542	0	0	11	461	236
Energy use (renewable)	MJ	712	560	118	6.05	0.0221	0	0	0.352	0.663	27.8

5 LIFE CYCLE IMPACT ASSESSMENT (LCIA)

This *Section* presents the impact assessment indicators and categories, as well as presenting the LCIA results.

5.1 IMPACT ASSESSMENT AND ENVIRONMENTAL INDICATORS

The impact indicators chosen for this study have been primarily sourced from the ReCiPe impact assessment method. The major collaborators of this method include RIVM and Radboud University, CML, and PRé. The basis for ReCiPe has been derived from the CML 2 baseline 2000 method and the eco-indicator 99 method and should be seen as the most recent update to both, which is why the mid-point element of ReCiPe has been chosen for this study.

The remaining indicators for renewable and non-renewable energy consumption have been adapted from the Cumulative Energy Demand method published by Ecoinvent 2.0 and adapted by PRé Consultants.

The environmental indicators and impact categories used in this study are described below:

Impact categories

- resource depletion (metal and fossil depletion);
- acidification;
- eutrophication;
- climate change (Global Warming Potential over 100 years [GWP 100]);
- ozone layer depletion;
- human toxicity;
- fresh water ecotoxicity;
- terrestrial ecotoxicity;
- photo-oxidant formation;

Non-impact indicators

- water depletion; and
- energy consumption.

For some impact categories, particularly human toxicity and fresh water and terrestrial ecotoxicity, there is a high level of uncertainty associated with the impact assessment methods. As a result, their adequacy for representing impacts is still the subject of some scientific discussion. The impact assessment reflects potential, not actual, impacts and takes no account of the local receiving environment.

Water depletion and energy consumption are not impacts but indicators of common interest.

5.1.1 Resource depletion

Resource depletion is a measure of the impact from consuming non-renewable natural resources such as iron ore, crude oil, coal, all of which are regarded as non-living.

The consumption of resources that cannot be regenerated, or may take thousands of years to do so, limits the options of future generations and can result in more expensive and damaging exploration and extraction of poorer or less available reserves.

Resource depletion is typically assessed by considering the rate of consumption and the scarcity of individual resources. Mineral and fossil resources were considered separately in this study and are further described below.

Mineral (metal) depletion

Mineral resource depletion considers the material resources extracted through mining operations. A reference unit was developed to assess metal depletion that considers the additional costs that society has to pay as a result of extraction of a mineral. This was expressed as a cost and was calculated by multiplying the marginal cost increase of a resource by the amount that is extracted through mining over a set time period. All mineral resources are then compared to the cost impact of Iron, resulting in an impact assessment indicator of kilograms of Iron equivalents.

Fossil depletion

The impact of extraction and consumption of fossil fuels was considered separately to metal depletion as it is difficult to consider oil and gas resources in terms of the different grades of extracted materials such as minerals.

The reference unit for fossil depletion was calculated by considering the energy content per kilogram of each hydrocarbon type and dividing this by energy content per kilogram of crude oil. The result is a fossil depletion impact for each oil, coal and gas type as kilograms of crude oil equivalents.

There is some uncertainty as to the quantity of accessible fossil fuel reserves in the world. As a result the measure and significance of fossil fuel depletion will vary with time.

5.1.2 *Acidification*

Acidification refers to sulfur, nitrogen and phosphorus compounds being deposited in soil and water which causes a change in acidity. Any change from the natural pH can have detrimental effects on plant and aquatic life.

Some common emissions that contribute to acidification include nitrogen oxides (NO_x), sulfur dioxide (SO_2) and ammonia (NH_3).

The ReCiPe method calculates characterization factors for emissions that contribute to acidification of soil relative to the acidification potential of SO_2. This is based upon a European geography over a 100 year time horizon.

5.1.3 *Eutrophication*

Eutrophication is defined as nutrient enrichment (typically from algae growth) in an aquatic environment, resulting in excess consumption and hence depletion of oxygen from the environment. This nutrient pollution is typically generated in aquatic environments from phosphorus or nitrogen compounds through sewage, storm water run-off, fertilizers or manure.

Typically, in freshwater ecosystems in Europe, phosphorus molecules are the limiting factor in eutrophication of an environment, whilst in marine ecosystems, nitrogen molecules are the limiting factor (1). As a result, freshwater and marine eutrophication were considered separately, using the ReCiPe method, and Eutrophication-inducing substances were considered in equivalents of kilograms of phosphorus and nitrogen for freshwater and marine ecosystems respectively.

5.1.4 *Climate change*

Climate change is a measure for the adverse environmental effect caused by man-made emissions of greenhouse gases that cause heat to be trapped in the atmosphere and so result in a temperature rise of the Earth's surface.

The Intergovernmental Panel on Climate Change (IPCC) has developed a characterization model to quantify the climate change impact of emissions released to the atmosphere. Emissions of different gases are given characterization factors, expressing the release of a gas in terms of its carbon dioxide equivalent (CO_2eq), depending upon its radiating force in relation to that of CO_2.

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(1) Crouzet *et al* (1999) *ReCiPe Manual* pg 63.

On calculating CO_2 equivalents, the residence time of the gases in the troposphere is taken into account and models for time periods of 20, 50 and 100 years have been developed. Commonly, a time horizon of 100 years is used as this reflects the long-term impacts of climate change. This was also chosen for this project.

For the purposes of this study, the substances contributing to climate change and their corresponding characterization factor (also known as Global Warming Potential, GWP) were based on IPCC 2007 data.

The contribution to climate change was calculated by summing the products of the amount of each emitted harmful material (m_i) and the corresponding characterization factor (GWP_i) as expressed in the following equation:

$$\text{Climate change} = \sum_i (m_i \times GWP_i)$$

Climate change and biogenic carbon

There are different approaches to calculating climate change impacts related to biogenic carbon. The approaches can be described as follows.

a) Accounting for carbon uptake: The biogenic CO_2 uptake is included in the calculations. During the growth phase of renewable materials (eg trees), CO_2 from the atmosphere is absorbed and converted through photosynthesis. This is accounted for in the calculation through a negative characterization value. At the end of the material's life, the carbon stored in the material is released again. This is accounted for in the calculation through a positive characterization value.

b) Assuming carbon neutrality: The uptake of CO_2 during the growth phase and the emission of CO_2 at end of life are assumed to outweigh each other. As such, the uptake and emission of CO_2 are disregarded in the calculations.

In this study, approach b) was applied.

Emissions of methane from biogenic materials (eg during landfill) are always accounted for.

5.1.5 Ozone layer depletion

Ozone layer depletion refers to the destruction of ozone in the stratosphere. This layer of ozone is crucial to life as it absorbs harmful solar ultraviolet radiation that can cause increased human health risk and have negative impacts on plant life and aquatic ecosystems if it reaches the troposphere.

Chlorine from chlorofluorocarbons (CFCs) and bromine from halons act as ozone-depleting substances and decrease the layer of ozone in the stratosphere, resulting in the potential for less ultraviolet radiation to be absorbed.

Ozone depletion is measured in terms of the capacity for an emission to reduce ozone in the stratosphere relative to the ozone reduction potential of trichlorofluoromethane (CFC-11) as a baseline. This is commonly expressed in terms of kilograms of CFC-11 per kilogram of emission of a substance.

5.1.6 Human toxicity

Human toxicity is a measure of the impact that chemicals emitted to the environment by human activities have on human health.

Some substances are poisonous to humans and can result in sickness or death through direct contact. Other substances can enter the food chain by accumulating in the living organisms that we eat (eg metals in fish) and, due to their properties, cause health effects.

Models are used to calculate the human toxicity potential, and are based on: the environmental media (air, water, soil etc.); behavior (eg movement between media, degradation, transformation, persistence in the food chain etc.); normal exposure (predicted daily intake) levels; and its toxicity on exposure.

The units of each toxic substance are converted to a common reference substance, for comparison purposes. The variables above are divided by the same variables for the reference substance.

The reference substance is expressed as kilograms of 1,4-dichlorobenzene equivalent (kg 1,4-DB eq.). This substance can be detected by smell at very low levels (i.e., it is used in mothballs and in toilet deodorizers).

For some impact categories, particularly human, there is a high level of uncertainty associated with the impact assessment methods. As a result, their adequacy for representing impacts is still the subject of some scientific discussion. The impact assessment reflects potential, not actual, impacts and takes no account of the local receiving environment.

5.1.7 Freshwater ecotoxicity

Aquatic toxicity is a measure of the impact that chemicals emitted by human activities have on aquatic ecosystems and the organisms that live in them. Toxicity in water can result in short or long term damage and even death of exposed organisms.

Models are used to calculate aquatic toxicity potential, and are based on the predicted concentration of the substance in the water and the effect factor, which is the toxic effect to organisms of the substance.

The toxic properties of each substance are converted to units of a common reference substance, to enable comparison. The toxicity variables above (eg predicted concentration etc.) are divided by the same variables for the reference substance.

For aquatic toxicity, the reference substance is expressed as kilograms of 1,4-dichlorobenzene equivalent (kg 1,4-DB eq.), which can often be found near sewage outlets.

For some impact categories, particularly fresh water ecotoxicity, there is a high level of uncertainty associated with the impact assessment methods. As a result, their adequacy for representing impacts is still the subject of some scientific discussion. The impact assessment reflects potential, not actual, impacts and takes no account of the local receiving environment.

5.1.8 Terrestrial ecotoxicity

Terrestrial ecotoxicity refers to the environmental persistence, accumulation in the human food chain and toxic effect of a chemical within soil.

There is an innumerable amount of chemicals that would have, to a varying degree, some persistence, build-up and effect upon the soil for a number of years. Common substances include heavy metals, inorganic and organic chemicals.

The ReCiPe method calculates this using a model that takes into account the fate, effect and exposure of a chemical to create five characterisation factors for its emissions. This model is called USES-LCA 2.0, with a scope that includes both agricultural and industrial soil in Western Europe.

For some impact categories, particularly terrestrial ecotoxicity, there is a high level of uncertainty associated with the impact assessment methods. As a result, their adequacy for representing impacts is still the subject of some scientific discussion. The impact assessment reflects potential, not actual, impacts and takes no account of the local receiving environment.

5.1.9 Photochemical oxidant formation

Photochemical oxidation (or photochemical oxidant formation) is a measure of the adverse effects from the formation of low-level ozone and other photo-oxidants formed through a complex reaction pattern involving sunlight and nitrogen oxides (NO_x) with certain air pollutants, such as volatile organic compounds (VOCs), nitrogen oxides (NO_x) and carbon monoxide (CO).

Models are used to calculate photochemical oxidation, and they are based on the mass of each released substance and the photochemical ozone creation potential (POCP) of the substance. POCP is a measure of how likely the substance will contribute towards smog formation. POCPs are calculated from the change in ozone concentration in a set volume of air with the introduction of the emission of a substance relative to the change in emission of ethylene.

The reference unit used for photochemical oxidation in ReCiPe is kilograms of non-methane volatile organic compounds (kg NMVOC) per kilogram of emissions. This is calculated based upon a ratio of the POCP for Ethylene.

5.1.10 *Other indicators*

Water depletion

Water consumption is becoming of increasing significance globally with regions experiencing extremes of water flow, from droughts to floods. Due to the difficulty in transporting water to affected areas, the need to assess and minimize the water consumption of a product or service over its lifetime is essential.

The ReCiPe environmental indicator for water depletion simply considers the consumption of fresh water from lakes, rivers, wells and of unspecified natural origin. Cooling water, process & turbine water and salt water use are excluded from the method. The method takes no account of local scarcity or local consumption.

Water consumption to be considered as an environmental impact requires local characterization factors that take into account water scarcity and local pressures. With the increasing interest in water resources it is expected that water resource impact methods will be developed in the near future.

Energy consumption

The consumption of various types of energy through the life cycle of a product or service is a useful way of providing an overview of the lifetime. Energy consumption has been split into non-renewable and renewable energy impact indicators. These indicators are based upon the Cumulative Energy Demand (CED) method developed by Ecoinvent.

Energy consumption is not an environmental impact but a common indicator used as a surrogate for environmental impacts including resource depletion, global warming. It is also a useful measure in supporting energy balances.

Non-renewable energy consumption

Non-renewable energy can be seen as a finite resource and typically considers energy produced from extracted materials such as oil and gas.

The non-renewable energy impact indicator considers energy from the production of fossil fuels such as gas, coal and peat, from nuclear origins such as uranium and from biomass from primary unsustainably managed forests.

Renewable energy consumption
Renewable energy is seen as a sustainable way of energy generation, relying upon natural surroundings for generation.

The renewable energy impact indicator considers the energy generated from sources such as wind power generation, solar & photovoltaic power, energy from geothermal origins, water such as hydropower and biomass from sustainably managed forests.

5.2 *CRADLE TO GRAVE LCIA RESULTS*

The total LCIA results for BlazeMaster® are presented in absolute values in *Table 5.1*, in percent contribution in *Table 5.2* and depicted graphically in *Figure* 5.1. (1). The main contributors to each impact category are discussed in *Section 5.3* and the relative contribution of different life cycle stages to the total environmental impact totals are presented in *Section 5.4*.

The key messages that can be extracted from the whole life results for each component of BlazeMaster® are summarized below.

- The impacts from across the life cycle of the **CPVC compound used for the pipe component far outweighs** the impact of all other components combined (i.e., fittings, solvent cement, hangers and screws). The results indicate that the pipe component accounts for nearly 64% or more of the impact in each category.
- The **CPVC compound production is the most significant material** that contributes to the impact. Including the fittings, the impact from the CPVC compounds account for >90% of the impact in all categories across the life cycle. These percent contributions are in line with the total mass that the components represent (refer to *Table 3.1*). This is driven by the PVC and chlorine materials for most impacts.

The impact results are further discussed by impact category and life cycle stage below.

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(1) The presentation of absolute impact values or relative contributions within the same figures or tables does not indicate equivalents between impact categories. The optional normalisation step described in ISO14040 has not been conducted due to the absence of appropriate normalisation data.

Table 5.1 Cradle to grave results for 304.8 m (1 000 ft) of BlazeMaster® by component

Impact	**Unit**	**Total**	**Pipe**	**Fittings**	**Hangers & screws**	**Solvent cement**
Resource depletion (metal)	kg Fe eq.	1,780	1,420	344	16	4.73
Resource depletion (fossil)	kg oil eq.	314	229	69.6	10.1	4.8
Acidification	kg SO$_2$ eq.	4.61	3.08	1.3	0.184	0.041
Eutrophication	kg P eq.	1.09E-02	7.71E-03	2.11E-03	8.91E-04	1.97E-04
Climate change	kg CO$_2$ eq.	874	611	223	28.6	11.7
Ozone depletion	kg CFC-11 eq.	1.74E-04	1.46E-04	2.51E-05	1.62E-06	1.29E-06
Human toxicity	kg 1,4-DB eq.	109	69.5	19	19.2	1.17
Freshwater ecotoxicity	kg 1,4-DB eq.	4.42	3.2	0.845	0.317	0.0573
Terrestrial ecotoxicity	kg 1,4-DB eq.	8.44E-02	6.06E-02	1.78E-02	4.97E-03	9.60E-04
Photochemical oxidant formation	kg NMVOC	2.88	1.93	0.62	0.156	0.18
Water depletion	m^3	8.14	6.66	1.26	0.166	0.0482
Energy use (non-renewable)	MJ	15,600	11,200	3,720	443	229
Energy use (renewable)	MJ	712	516	173	8.54	14.5

Note: Numbers rounded to three significant figures

Table 5.2 Cradle to grave results for BlazeMaster® (%) by component

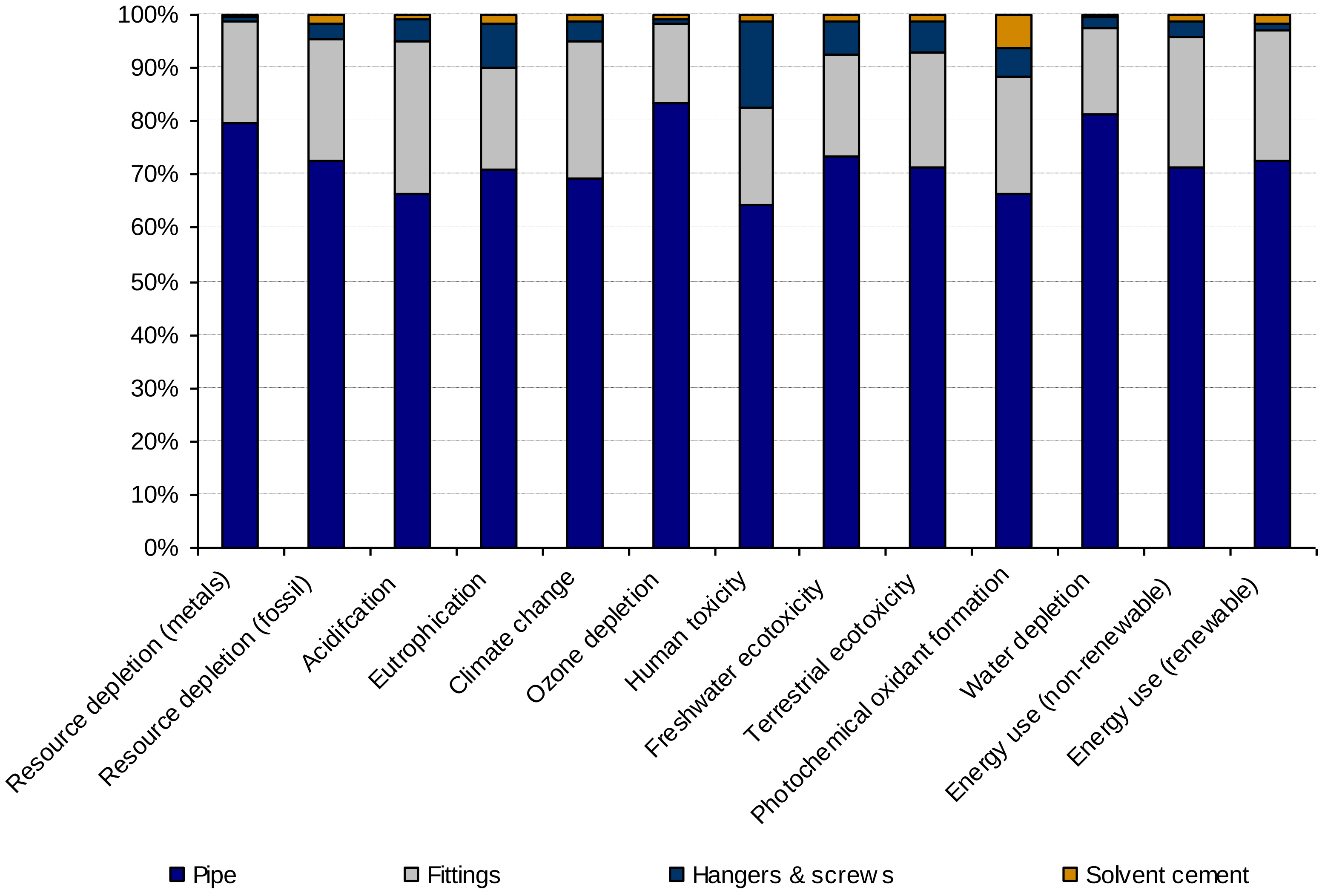
Impact	**Unit**	**Total**	**Pipe**	**Fittings**	**Hangers & screws**	**Solvent cement**
Resource depletion (metal)	kg Fe eq.	100%	80%	19%	1%	0%
Resource depletion (fossil)	kg oil eq.	100%	73%	22%	3%	2%
Acidification	kg SO$_2$ eq.	100%	67%	28%	4%	1%
Eutrophication	kg P eq.	100%	71%	19%	8%	2%
Climate change	kg CO$_2$ eq.	100%	70%	26%	3%	1%
Ozone depletion	kg CFC-11 eq.	100%	84%	14%	1%	1%
Human toxicity	kg 1,4-DB eq.	100%	64%	17%	18%	1%
Freshwater ecotoxicity	kg 1,4-DB eq.	100%	72%	19%	7%	1%
Terrestrial ecotoxicity	kg 1,4-DB eq.	100%	72%	21%	6%	1%
Photochemical oxidant formation	kg NMVOC	100%	67%	22%	5%	6%
Water depletion	m^3	100%	82%	15%	2%	1%
Energy use (non-renewable)	MJ	100%	72%	24%	3%	1%
Energy use (renewable)	MJ	100%	72%	24%	1%	2%

5.3 RESULTS BY IMPACT

The results for each environmental impact and total energy demand are discussed in Sections *5.3.3* through *5.3.12*.

Figure 5.2 to *Figure 5.14* provide further information outlining the relative contribution of individual processes in the system and how the impacts of these processes flow through the life cycle stages.

Figure 5.1 Cradle to grave results for BlazeMaster® (%) by component



5.3.1 *Metal depletion*

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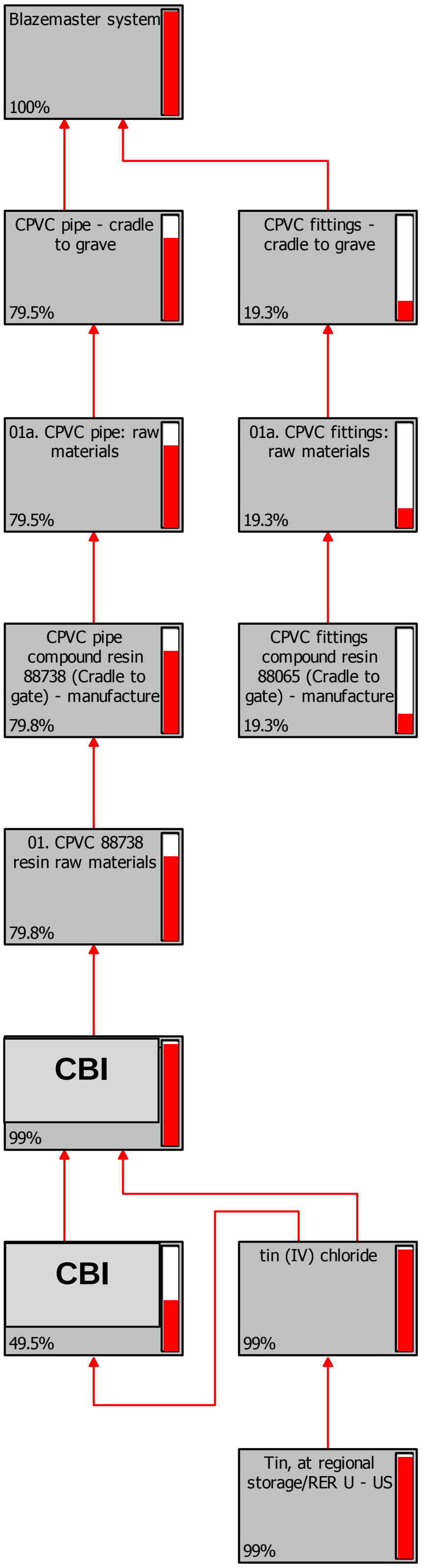
Figure 5.2 *Metal depletion network flow chart*

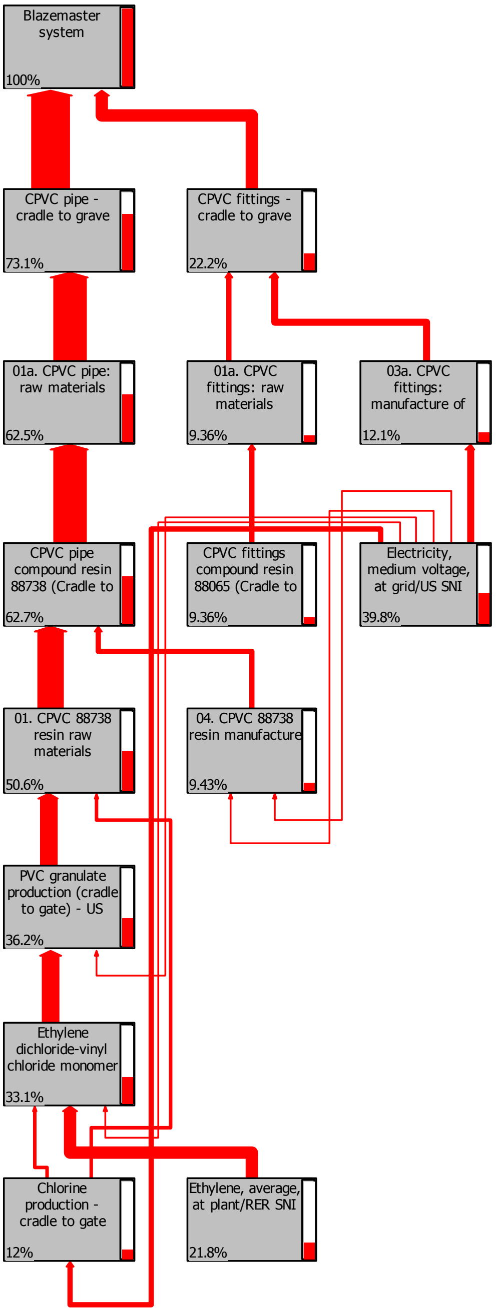


5.3.2 *Fossil depletion*

The fossil depletion is from a combination of natural gas (36%), crude oil (31%) and coal (30%). The majority of the fossil resources are used in electricity production (40%) and ethylene production (22%) for the PVC.

The main contribution to fossil resource consumption for electricity generation in the US is through the use of coal and natural gas as energy sources. The use of ethylene through PVC production has a significant impact on fossil resource depletion, as it is typically produced from thermal cracking of hydrogen feedstocks. Additionally, thermal cracking is typically undertaken using steam, heated using natural gas furnaces.

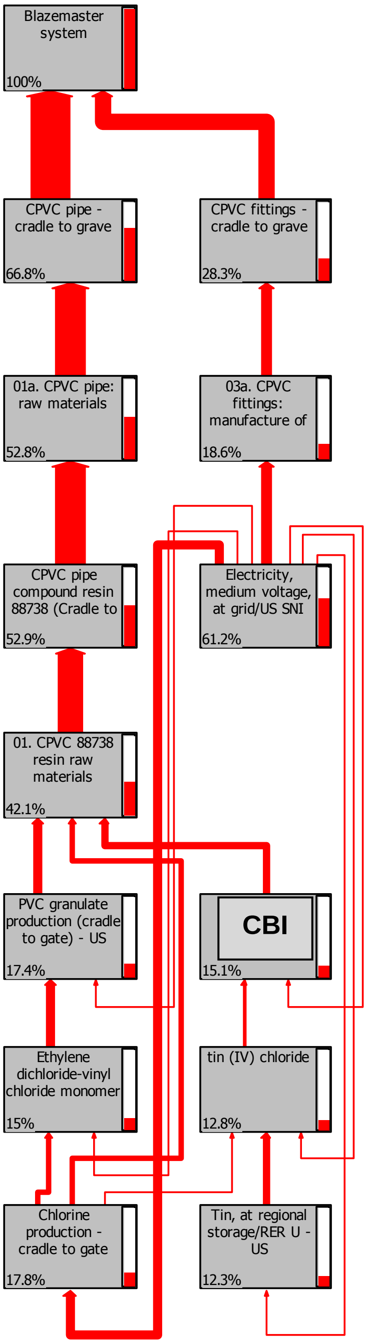
Figure 5.3 Fossil depletion network flow chart



5.3.3 *Acidification*

SOx (74%) and NOx (24%) emissions are the main contributors to terrestrial acidification. These emissions occur during the production of electricity (61%) that is used to manufacture the raw materials and actual BlazeMaster® product. During electricity production, NOx and SOx are typically emitted through burning of coal as a fuel source. [CONFIDENTIAL BUSINESS INFORMATION] The acidification impact of tin is primarily from emissions through electricity generation, and through NOx and ammonia emissions from blasting during the mining process.

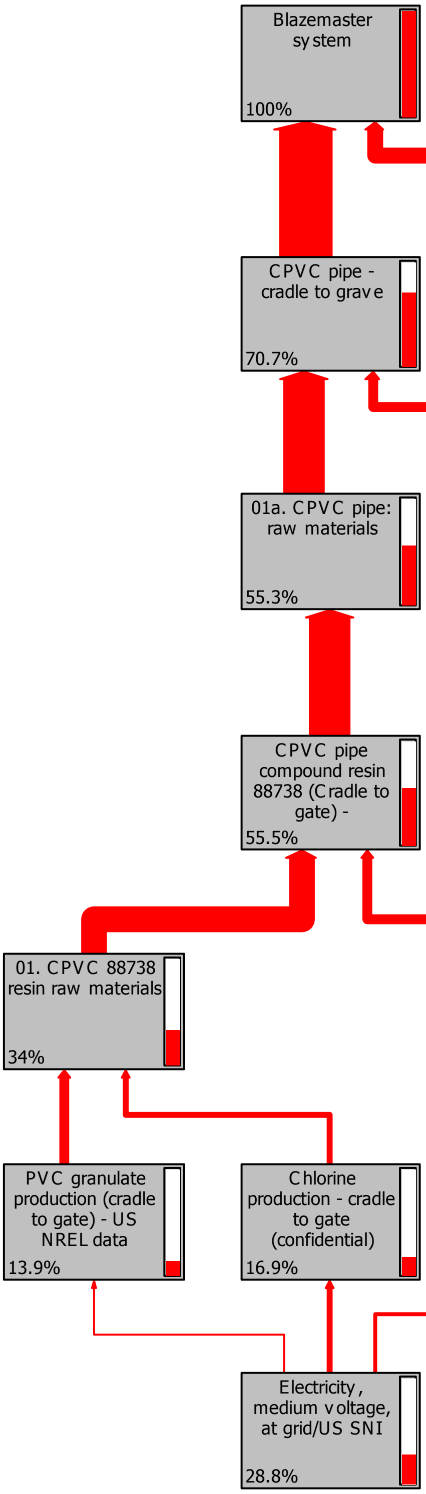
Figure 5.4 Acidification network flow chart



5.3.4 *Eutrophication*

Eutrophication in freshwater is mainly (92%) from phosphate, which originates from electricity production (29%) and from wastewater treatment (15%) applied during the production of the raw materials and BlazeMaster®. The landfill of coal ash from coal burnt for electricity generation generates the main proportion of phosphates contributing towards the eutrophication impact.

Figure 5.5 Eutrophication network flow chart

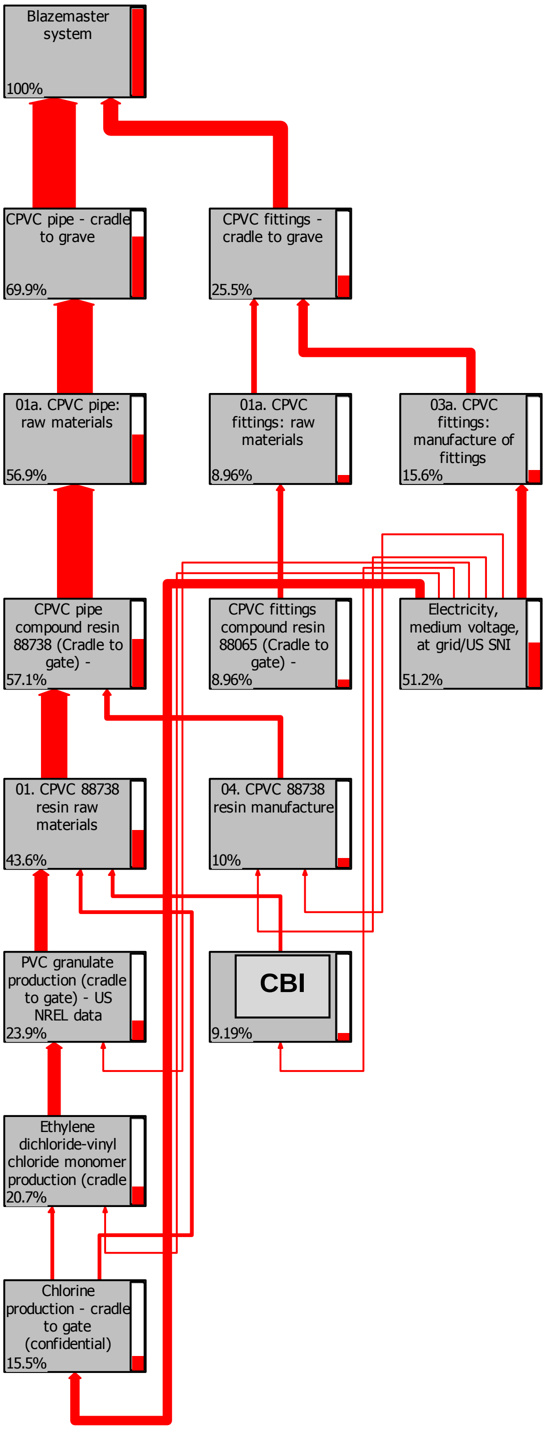


5.3.5 *Climate change*

As expected with a plastic product, the majority (88%) of the climate change impact is from CO_2 emissions. The majority of these emissions are from electricity (51%) used during the production of the raw materials and BlazeMaster®.

The production of ethylene (7%) and the steam needed for the chemical processes (6%) are significant contributors to climate change.

Figure 5.6 Climate change network flow chart

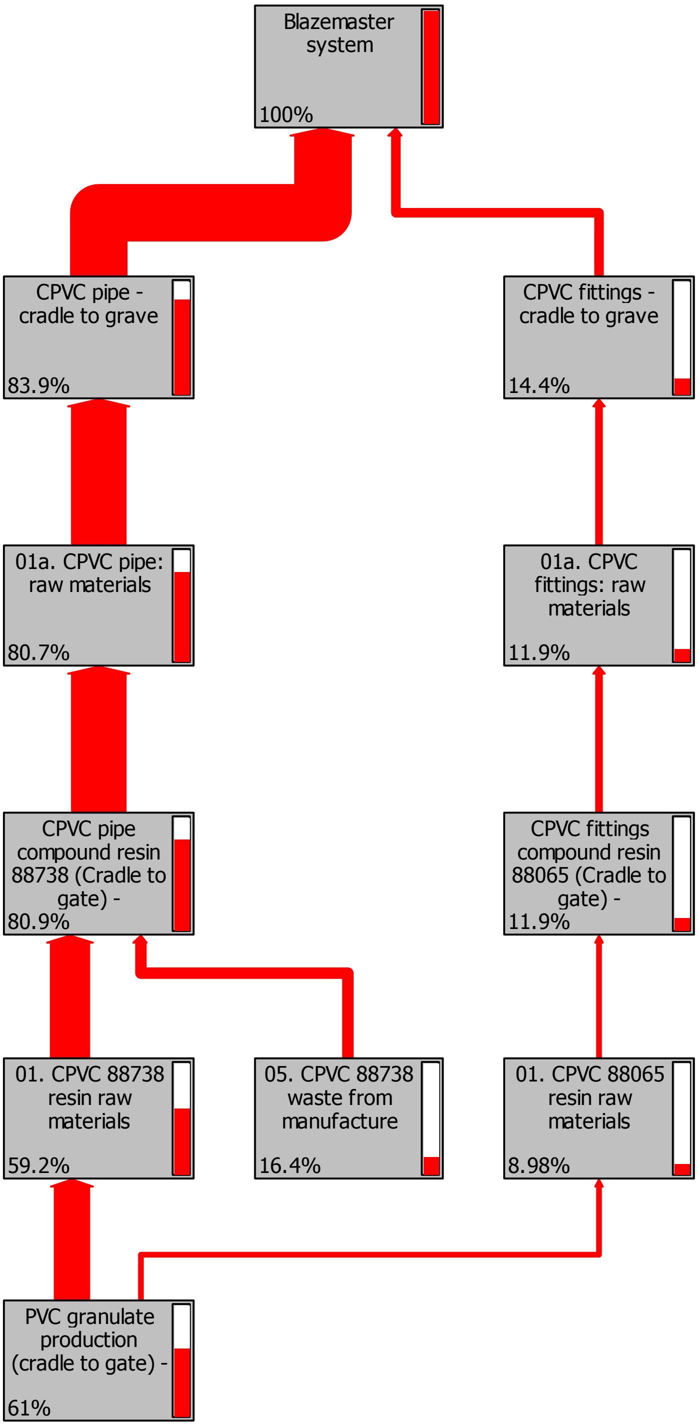


Source: ERM SimaPro model (2009)

5.3.6 Ozone depletion

Methane (mainly tetrachloro-, CFC-10 and trichlorofluoro-, CFC-11) emissions from the production of PVC account for 76% of the ozone depletion impact. 61% of the ozone depletion is from the production of the PVC granulate and 16% is from the emissions arising from formation of the CPVC pipe compound. Refrigerants are typically used in these processes in conjunction with water for cooling purposes.

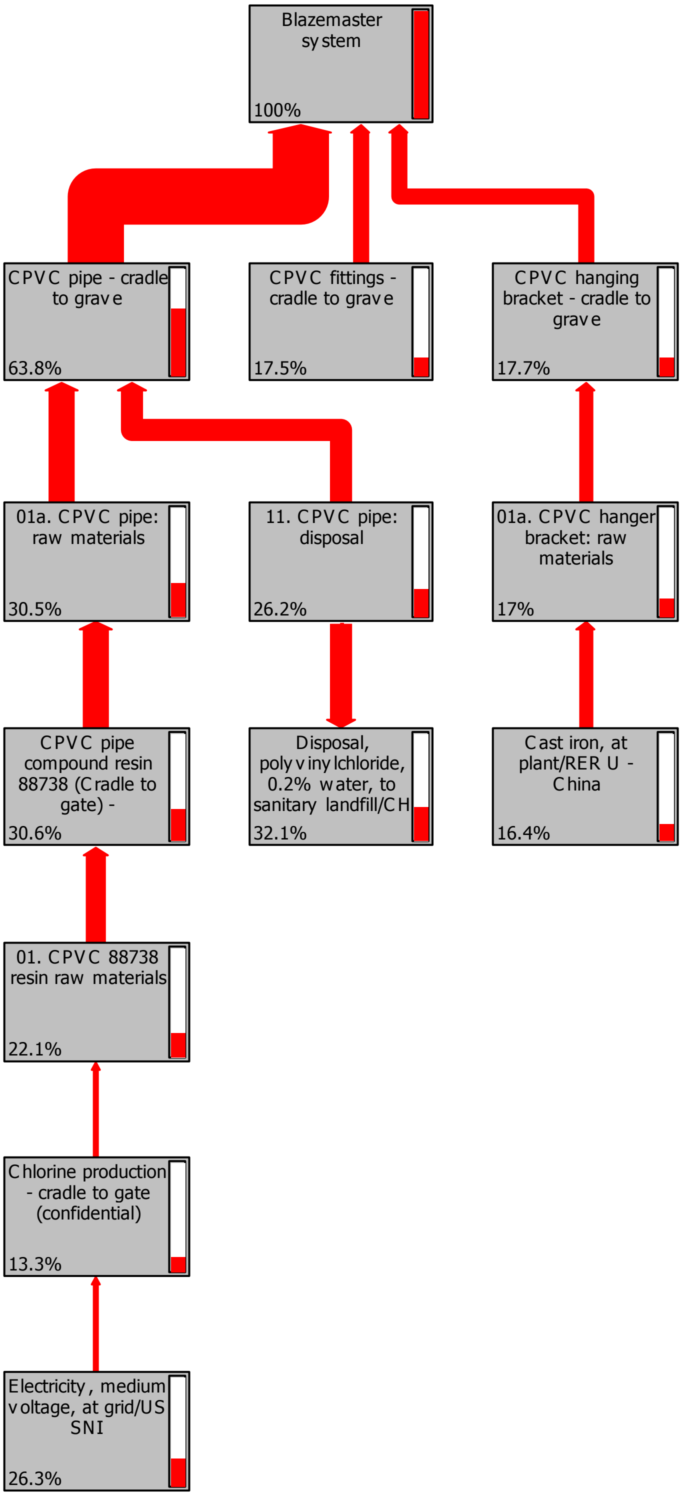
Figure 5.7 Ozone depletion network flow chart



5.3.7 Human toxicity

The disposal of the PVC from pipes and fittings account for 32% of the human toxicity impact, while the electricity and chlorine used in production account for 26% and 6%, respectively. Barium water emissions (24%) and mercury (21%) air emissions from PVC disposal in landfill are the leading substances that contribute towards this impact category.

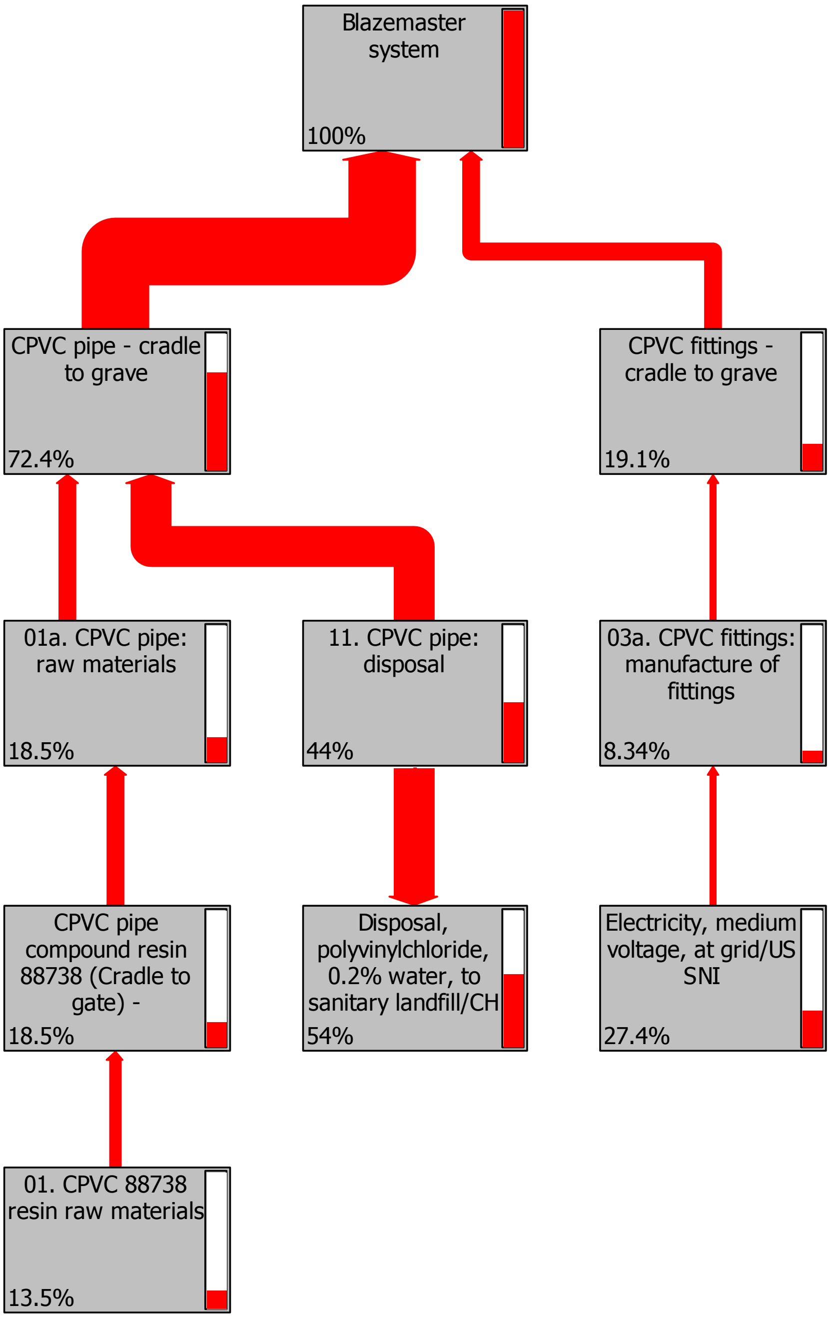
Figure 5.8 Human toxicity network flow chart



5.3.8 Freshwater ecotoxicity

The majority of freshwater ecotoxicity originates from the disposal of PVC in landfill (54%) and electricity generation (27%). The substances that contribute towards this impact are vanadium (39%), bromine (27%) and nickel (13%) leachate to water through PVC landfill. The impact of electricity generation arises from the release of bromines from natural gas extraction.

Figure 5.9 Freshwater ecotoxicity network flow chart

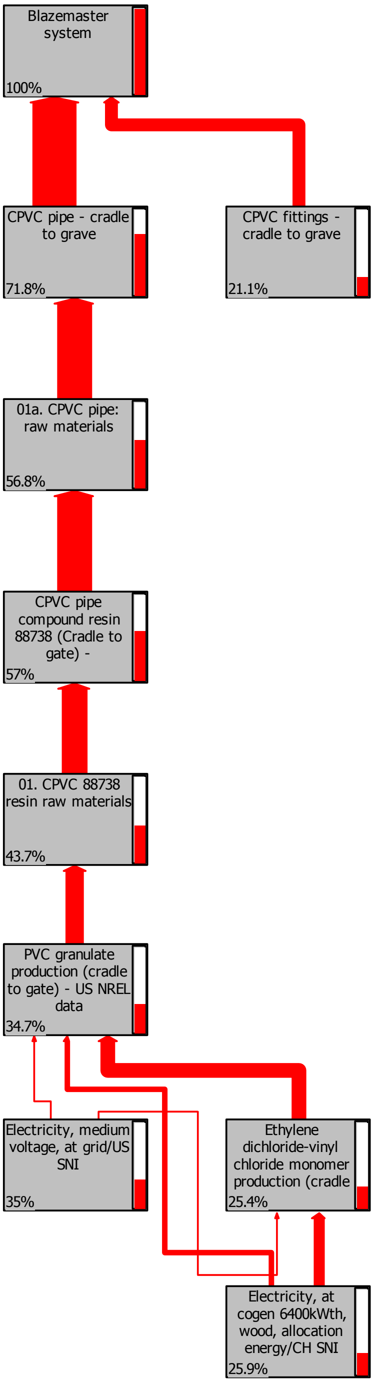


5.3.9 Terrestrial ecotoxicity

Terrestrial ecotoxicity is mainly from phosphorus (41%) in the soil and bromine (24%) water emissions. These emissions are mainly from electricity production (61%) and disposal of the CPVC at end of life (8%).

The majority of bromine emissions to water are from natural gas extraction and phosphorus emissions to soil from disposal of wood ash burnt for electricity generation.

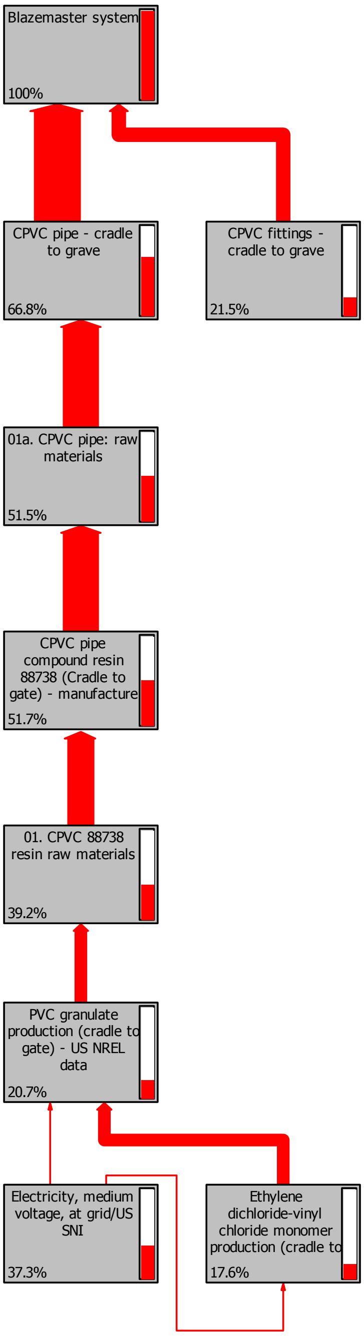
Figure 5.10 Terrestrial ecotoxicity network flow chart



5.3.10 Photochemical oxidant formation

NOx (70%) emissions from the electricity used to manufacture the raw materials and BlazeMaster® and from transportation represent the most significant contribution towards photochemical oxidant formation. 37% of the overall impact is from electricity generation, approximately 11% from transport and 7% from ethylene production. NOx emissions during electricity generation primarily arise from the burning of coal as a fuel. The impact of transportation with respect to photochemical oxidant formation is from NOx emissions to air created from the combustion of fuels, particularly diesel fuel in lorry transport.

Figure 5.11 Photochemical oxidant formation network flow chart

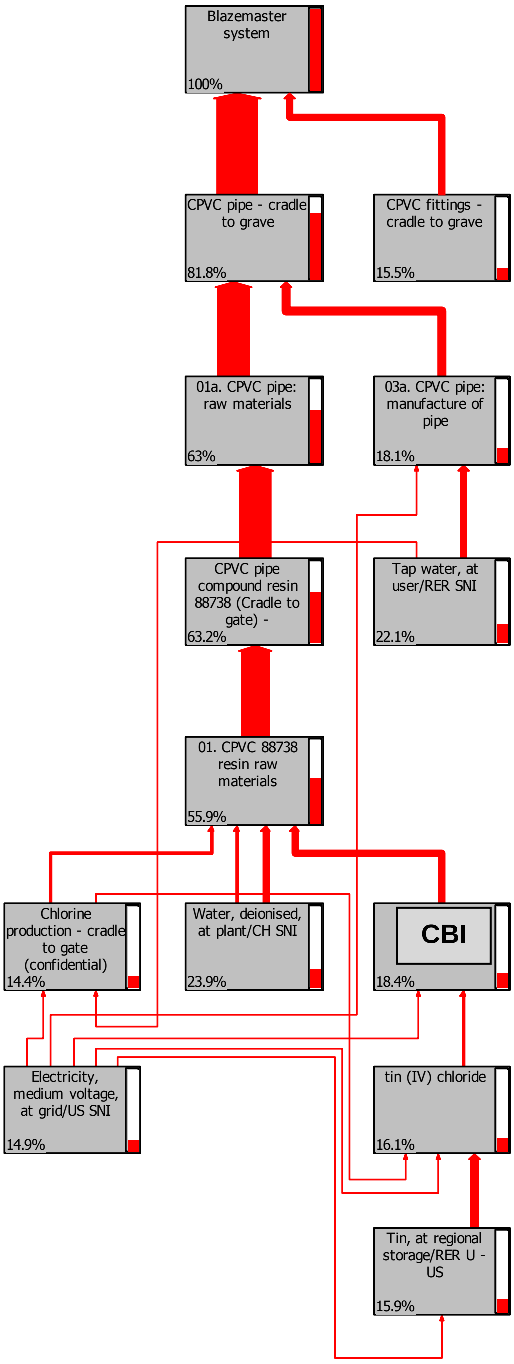


5.3.11 *Water depletion*

Although a large proportion of the water used is from direct inputs into CPVC compound production (24%) and for cooling/cleaning during pipe manufacture and raw material production (22%), a significant amount is used in most production processes, including: 16% in tin production and 15% from electricity production.

Water consumed in electricity generation is mainly from its use in nuclear power generation. The impact of water used in electricity generation methods such as hydropower was excluded from the scope of the study.

Figure 5.12 Water depletion network flow chart



5.3.12 *Energy consumption*

The majority of the energy, approximately 96%, used throughout the life cycle is from non-renewable sources. Fossil fuels account for 80% of the total energy demand. The total energy demand is 16 490 MJ, which is equivalent to 4 581 kWh for 1 000 feet of BlazeMaster®. The split between non-renewable and renewable energy sources is largely based upon energy sources used to produce the US electricity mix.

Figure 5.13 Non renewable energy consumption network flow chart

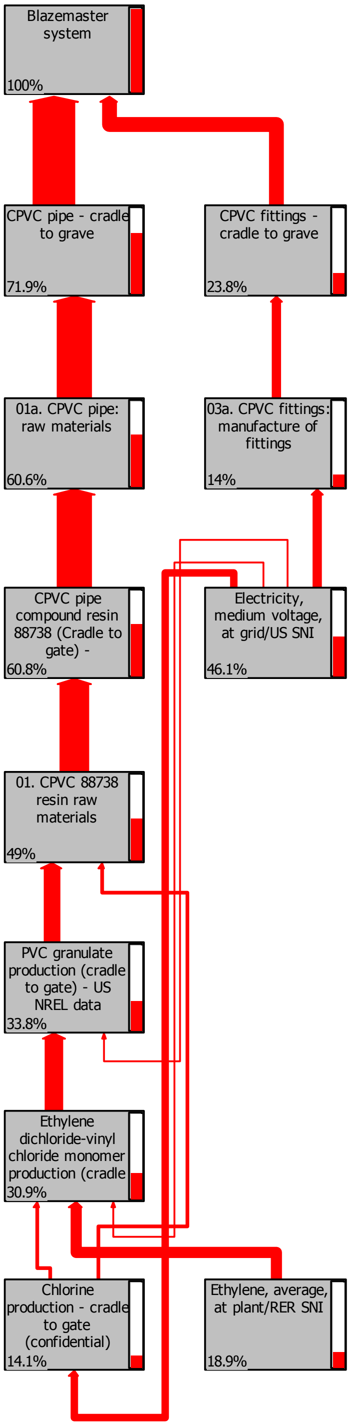
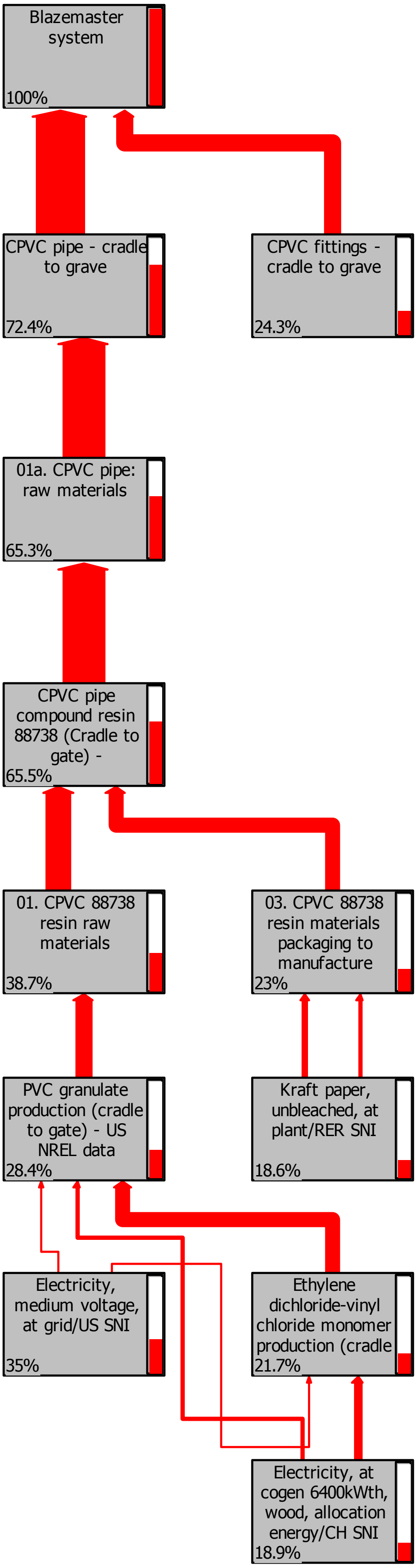


Figure 5.14 Renewable energy consumption network flow chart



5.4 *CRADLE TO GRAVE RESULTS BY LIFE CYCLE STAGE*

Table 5.3 and *Table 5.4* present the whole life results for BlazeMaster® by life cycle stage in absolute numbers and percent, respectively. *Figure 5.15* presents the whole life results graphically.

The key messages that can be extracted from the whole life results for the life cycle stages are summarized below.

- **Raw material production** is the **most significant contributor** to all impact categories, with the exception of freshwater ecotoxicity.

- **Manufacturing** is the second most significant contributor, accounting for up to 27% of the total impact.

- Disposal of **PVC in landfill** influences toxicity impact categories.

- The impact from wholesale, transport and packaging is very low.

Table 5.3 Whole life results for 304.8 m (1 000 ft) of BlazeMaster® by life cycle stage

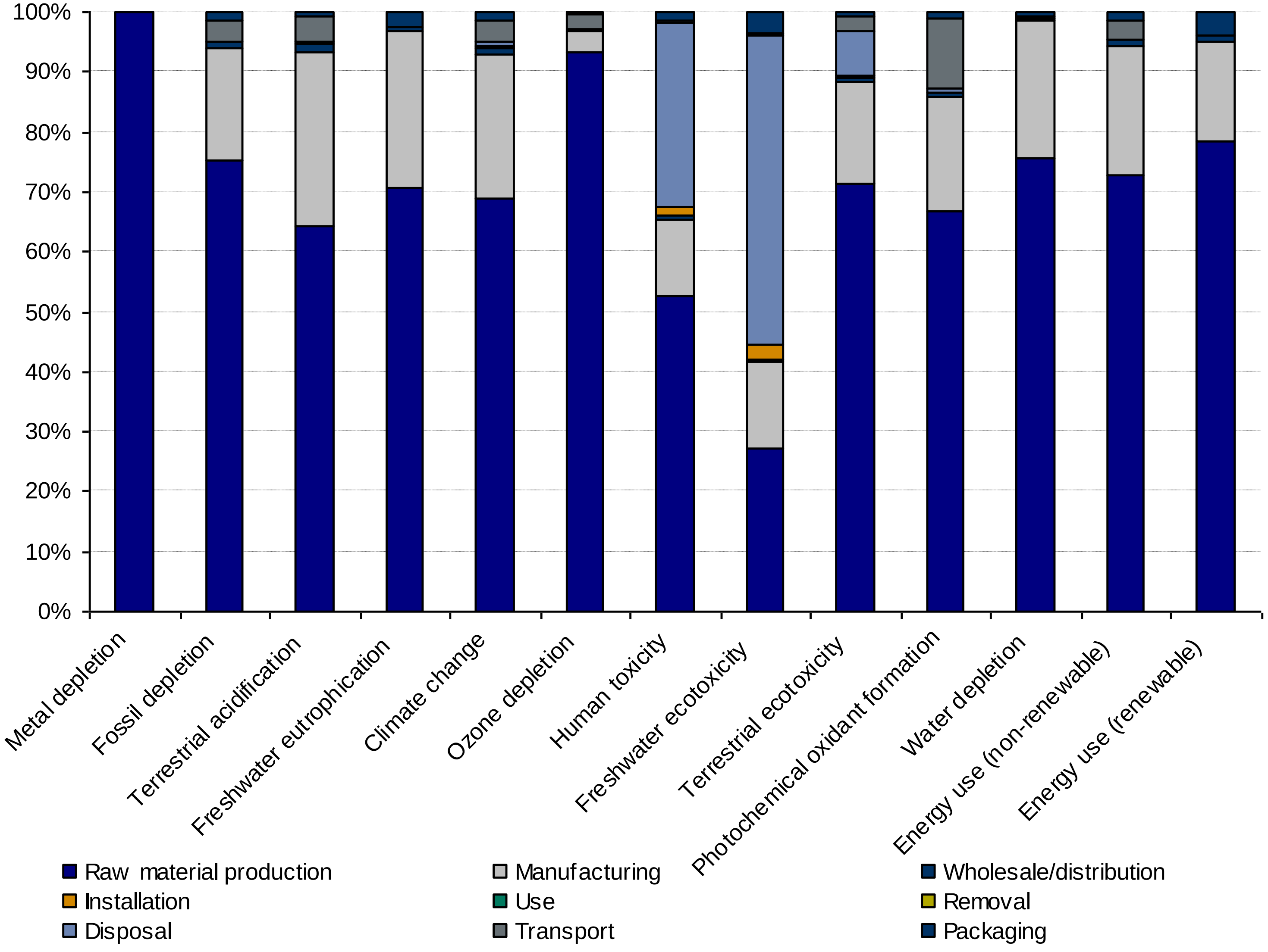
Impact category	**Unit**	**Total**	**Raw material production**	**Manu-facturing**	**Wholesale / distrib**	**Installation**	**Use**	**Removal**	**Disposal**	**Transport**	**Packaging**
Resource depletion (metal)	kg Fe eq.	1,780	1,780	1.58	0.013	2.80E-05	0	0	4.29E-04	1.44E-03	0.0839
Resource depletion (fossil)	kg oil eq.	314	236	58.9	3.03	0.0105	0	0	0.222	10.9	4.82
Acidification	kg SO_2 eq.	4.61	2.97	1.33	0.0684	2.37E-04	0	0	0.00527	0.198	0.035
Eutrophication	kg P eq.	1.09E-02	7.71E-03	2.84E-03	7.62E-05	1.66E-07	0	0	8.93E-07	5.27E-06	2.72E-04
Climate change	kg CO_2 eq.	874	601	211	10.9	0.35	0	0	8.16	31.8	11
Ozone depletion	kg CFC-11 eq.	1.74E-04	1.63E-04	5.85E-06	2.95E-07	3.89E-09	0	0	8.22E-08	4.84E-06	3.80E-07
Human toxicity	kg 1,4-DB eq.	109	57.3	13.9	0.693	1.43	0.0277	0	33.6	0.437	1.54
Freshwater ecotoxicity	kg 1,4-DB eq.	4.42	1.21	0.626	0.0294	0.0973	3.40E-06	0	2.29	0.0152	0.153
Terrestrial ecotoxicity	kg 1,4-DB eq.	8.44E-02	6.03E-02	1.41E-02	7.15E-04	2.63E-04	5.62E-06	0	6.18E-03	2.17E-03	5.84E-04
Photochemical oxidant formation	kg NMVOC	2.88	1.83	0.515	0.0261	4.90E-04	0.148	0	0.0111	0.319	0.0328
Water depletion	m^3	8.14	6.16	1.87	0.0294	1.18E-04	0	0	0.00161	0.0291	0.046
Energy use (non-renewable)	MJ	15,600	11,300	3,370	174	0.542	0	0	11	461	236
Energy use (renewable)	MJ	712	560	118	6.05	0.0221	0	0	0.352	0.663	27.8

Note: Numbers rounded to three significant figures

Table 5.4 Whole life results for 304.8 m (1 000 ft) of BlazeMaster® by life cycle stage (%)

Impact category	**Unit**	**Total**	**Raw material production**	**Manu-facturing**	**Wholesale / distrib**	**Installation**	**Use**	**Removal**	**Disposal**	**Transport**	**Packaging**
Resource depletion (metal)	kg Fe eq.	100%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Resource depletion (fossil)	kg oil eq.	100%	75%	19%	1%	0%	0%	0%	0%	3%	2%
Acidification	kg SO_2 eq.	100%	64%	29%	1%	0%	0%	0%	0%	4%	1%
Eutrophication	kg P eq.	100%	71%	26%	1%	0%	0%	0%	0%	0%	2%
Climate change	kg CO_2 eq.	100%	69%	24%	1%	0%	0%	0%	1%	4%	1%
Ozone depletion	kg CFC-11 eq.	100%	94%	3%	0%	0%	0%	0%	0%	3%	0%
Human toxicity	kg 1,4-DB eq.	100%	53%	13%	1%	1%	0%	0%	31%	0%	1%
Freshwater ecotoxicity	kg 1,4-DB eq.	100%	27%	14%	1%	2%	0%	0%	52%	0%	3%
Terrestrial ecotoxicity	kg 1,4-DB eq.	100%	71%	17%	1%	0%	0%	0%	7%	3%	1%
Photochemical oxidant formation	kg NMVOC	100%	64%	18%	1%	0%	5%	0%	0%	11%	1%
Water depletion	m^3	100%	76%	23%	0%	0%	0%	0%	0%	0%	1%
Energy use (non-renewable)	MJ	100%	72%	22%	1%	0%	0%	0%	0%	3%	2%
Energy use (renewable)	MJ	100%	79%	17%	1%	0%	0%	0%	0%	0%	4%

Figure 5.15 Whole life results for 304.8 m (1 000 ft) of BlazeMaster® by life cycle stage (%)



5.5 CRADLE TO GATE LCIA RESULTS

The cradle to gate results are presented by component and life cycle stage below. The main conclusions that can be drawn from the results are summarized below.

1. The production of raw materials used in the pipe is the main contributor to all impact categories.
2. The fittings contribute to approximately 23% of the impact, on average, for each category.
3. The metal used to manufacture the hangers and screws have a small but noteworthy contribution toward human toxicity and freshwater ecotoxicity.

Table 5.5 Cradle to gate results for BlazeMaster® by component

Impact	Unit	Total	Pipe	Fittings	Hangers & screws	Solvent cement
Resource depletion (metal)	kg Fe eq.	1,710	1,350	344	16	4.73
Resource depletion (fossil)	kg oil eq.	288	207	67.6	8.35	4.74
Acidification	kg SO_2 eq.	4.22	2.76	1.27	0.141	0.0401
Eutrophication	kg P eq.	1.03E-02	7.22E-03	2.01E-03	8.90E-04	1.97E-04
Climate change	kg CO_2 eq.	795	545	215	23.4	11.5
Ozone depletion	kg CFC-11 eq.	1.63E-04	1.37E-04	2.45E-05	8.35E-07	1.27E-06
Human toxicity	kg 1,4-DB eq.	69.9	36.1	14	19.2	0.688
Freshwater ecotoxicity	kg 1,4-DB eq.	1.81	0.961	0.507	0.315	0.0268
Terrestrial ecotoxicity	kg 1,4-DB eq.	7.26E-02	5.06E-02	1.64E-02	4.63E-03	8.62E-04
Photochemical oxidant formation	kg NMVOC	2.34	1.62	0.583	0.104	0.0297
Water depletion	m^3	7.74	6.29	1.24	0.161	0.048
Energy use (non-renewable)	MJ	14,400	10,100	3,620	367	227
Energy use (renewable)	MJ	664	481	161	8.43	14.5

Note: Numbers rounded to three significant figures

Table 5.6 Cradle to gate results for BlazeMaster® (%) by component

Impact	Total	Pipe	Fittings	Hangers & screws	Solvent cement
Resource depletion (metal)	100%	79%	20%	1%	0%
Resource depletion (fossil)	100%	72%	23%	3%	2%
Acidification	100%	65%	30%	3%	1%
Eutrophication	100%	70%	20%	9%	2%
Climate change	100%	69%	27%	3%	1%
Ozone depletion	100%	84%	15%	1%	1%

Impact	Total	Pipe	Fittings	Hangers & screws	Solvent cement
Human toxicity	100%	52%	20%	27%	1%
Freshwater ecotoxicity	100%	53%	28%	17%	1%
Terrestrial ecotoxicity	100%	70%	23%	6%	1%
Photochemical oxidant formation	100%	69%	25%	4%	1%
Water depletion	100%	81%	16%	2%	1%
Energy use (non-renewable)	100%	70%	25%	3%	2%
Energy use (renewable)	100%	72%	24%	1%	2%

Figure 5.16 *Cradle to grave results for BlazeMaster® (%) by component*

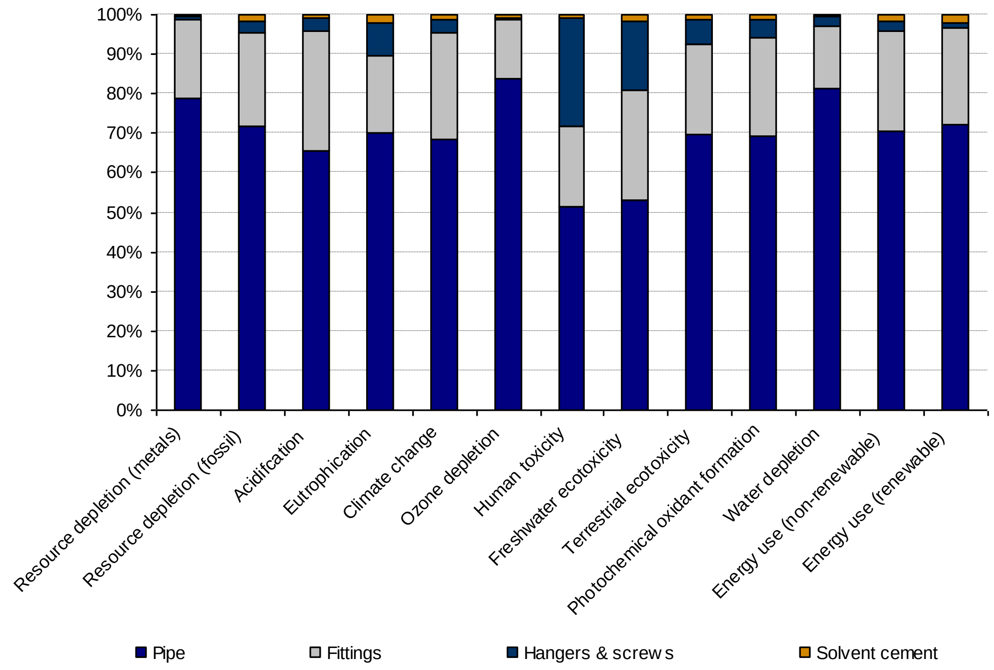


Table 5.7 *Cradle to gate results for BlazeMaster® by life cycle stage*

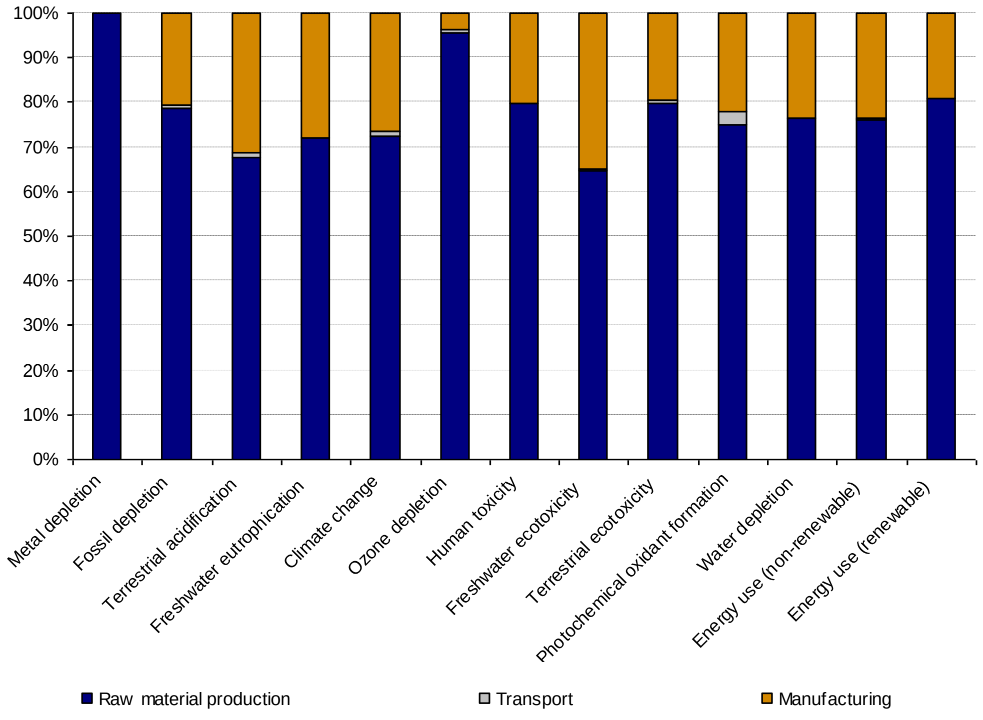
Impact category	Unit	Total	Raw material production	Transport	Manufacturing
Metal depletion	kg Fe eq.	1,710	1,710	3.02E-04	1.65
Fossil depletion	kg oil eq.	288	227	2.29	58.9
Terrestrial acidification	kg SO_2 eq.	4.22	2.85	0.039	1.32
Freshwater eutrophication	kg P eq.	1.03E-02	7.42E-03	1.11E-06	2.89E-03
Climate change	kg CO_2 eq.	795	577	6.69	212
Ozone depletion	kg CFC-11 eq.	1.63E-04	1.56E-04	1.02E-06	5.97E-06
Human toxicity	kg 1,4-DB eq.	69.9	55.7	0.0911	14.1
Freshwater ecotoxicity	kg 1,4-DB eq.	1.81	1.17	3.20E-03	0.634
Terrestrial ecotoxicity	kg 1,4-DB eq.	7.26E-02	5.80E-02	4.63E-04	1.41E-02
Photochemical oxidant formation	kg NMVOC	2.34	1.76	0.0672	0.515

Impact category	Unit	Total	Raw material production	Transport	Manufacturing
Water depletion	m^3	7.74	5.92	6.13E-03	1.81
Energy use (non-renewable)	MJ	14,400	10,900	97	3,360
Energy use (renewable)	MJ	664	538	0.14	126

Table 5.8 *Cradle to gate results for BlazeMaster® (%) by life cycle stage*

Impact category	Total	Raw material production	Transport	Manufacturing
Metal depletion	100%	100%	0%	0%
Fossil depletion	100%	79%	1%	20%
Terrestrial acidification	100%	68%	1%	31%
Freshwater eutrophication	100%	72%	0%	28%
Climate change	100%	73%	1%	27%
Ozone depletion	100%	96%	1%	4%
Human toxicity	100%	80%	0%	20%
Freshwater ecotoxicity	100%	65%	0%	35%
Terrestrial ecotoxicity	100%	80%	1%	19%
Photochemical oxidant formation	100%	75%	3%	22%
Water depletion	100%	76%	0%	23%
Energy use (non-renewable)	100%	76%	1%	23%
Energy use (renewable)	100%	81%	0%	19%

Figure 5.17 *Cradle to gate results for BlazeMaster® (%) by life cycle stage*



6 SENSITIVITY ANALYSES

Two sensitivity analyses were conducted in this LCA to account for the variability related to replacing the use of human labor with a mechanized process during installation and removal as well as future recycling scenarios at end of life.

6.1 HUMAN LABOR

Manual labor is typically excluded from conventional LCAs as it is a social and economic issue. However, an exploratory sensitivity analysis was carried out to estimate the scale of impact that could be associated with the effort for installation and removal of BlazeMaster® pipe should it be provided through mechanical means instead of via human labor.

Human labor is a necessary production factor for the installation and removal of BlazeMaster® pipe. The resulting mechanization burdens are assumed equivalent to work-calories and commuting associated with installation and removal of the BlazeMaster® pipe through manual labor. This energy demand excludes the energy requirements of the installation worker in a resting state. The data used for this sensitivity analysis is noted below.

- Painting, remodeling: 5.62 kcal/min/person (Ref: Gabor Doka (1))
- Installation: 150 hours (9000 minutes) (Ref: Lubrizol)
- Removal: 150 hours (estimated by ERM)
- 1 kcal = 4.184 kJ = 0.001163 kWh (Ref: Engineering Toolbox (2))

Therefore, it was estimated that installation of 1 000 ft of pipe is equivalent to:

$$\textit{Total energy} = 5.62\ \textit{kcal/min} * 9000\ \textit{min} * 0.001163\ \textit{kWh/kcal} = 58.8\ \textit{kWh}$$

It was assumed that the time taken to remove the BlazeMaster® pipe is the same as installation. The same energy is therefore required for removal, or a total of 117.6 kWh for installation and removal of the pipe.

The change in impact when accounting for the replacement of human labor by automation or mechanical assistance is detailed in *Table* 6.1.

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(1) As documented on PRé LCA Discussion List; this represents an average for a 70 kg person (April 2009) Available at: http://www.pre.nl/discussion/default.htm

(2) http://www.engineeringtoolbox.com/unit-converter-d_185.html#Energy

Table 6.1 Impact of human labor (if replaced by 117.6 kWh of electricity)

Impact category	**Unit**	**Including manual labor**	**Excluding manual labor**	**Percent change**
Resource depletion (metal)	kg Fe eq.	1,780	1,780	0%
Resource depletion (fossil)	kg oil eq.	339	314	8%
Acidification	kg SO_2 eq.	5.17	4.61	12%
Eutrophication	kg P eq.	1.15E-02	1.09E-02	6%
Climate change	kg CO_2 eq.	115	109	6%
Ozone depletion	kg CFC-11 eq.	4.66	4.42	5%
Human toxicity	kg 1,4-DB eq.	9.03E-02	8.44E-02	7%
Freshwater ecotoxicity	kg 1,4-DB eq.	3.1	2.88	8%
Terrestrial ecotoxicity	kg 1,4-DB eq.	8.38	8.14	3%
Photochemical oxidant formation	kg NMVOC	17,000	15,600	9%
Water depletion	m^3	762	712	7%
Energy use (non-renewable)	MJ	1,780	1,780	0%
Energy use (renewable)	MJ	339	314	8%

The results of this sensitivity analysis indicate that installation and removal, be it manual or mechanized, is not of consequence in purely environmental terms.

6.2 *END OF LIFE*

Currently in the US, recycling is not an option for BlazeMaster® at end of life. However, due to the relatively long life of the product (i.e., 50 years) it is feasible that recycling operations may be put in place in the future.

This sensitivity analysis assessed the reduced impact from sending less CPVC to landfill by assuming recycling rates of 5%, 10%, 15%, 20%, 30%, 40%, 50% and 75%.

Recycling the BlazeMaster® at end of life has assumed an electricity requirement for recycling of 0.6 kWh per kg of recycled material (1), a 100% conversion efficiency and a substitution benefit of the CPVC compound. The actual benefits of recycling will depend on the end application, the conversion requirements and efficiency and the substituted materials.

The results of this sensitivity analysis indicate that environmental improvement of more than 50% can be reached when the recycling rate is as high as 75%. With lower rates of recycling, the savings are less – these are depicted in *Figure 6.1*. Some impacts, such as toxicity, are associated with leachate and gaseous emissions from landfill. The reliability and appropriateness of these impacts should be considered, as there remains scientific uncertainty over the

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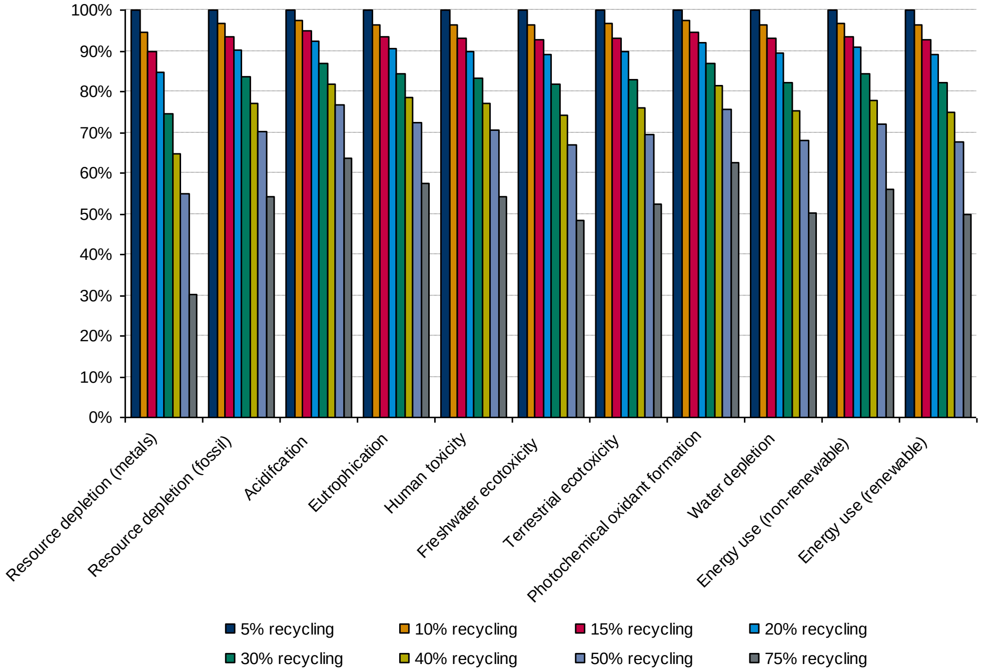
(1) Energy requirements from the process for recycling mixed plastics within SimaPro software titled "Recycling mixed plastics/RER U" PRé Consultants, 2007

degradation of wastes, the degradation products and the allocation of landfill emissions to the wastes disposed of.

Figure 6.1 *Impact of recycling CPVC*



7 CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to inform Lubrizol of the environmental profile and performance of the BlazeMaster® fire sprinkler system. The study was delivered using high levels of primary data and is considered to be both a robust and accurate representation of Lubrizol's BlazeMaster® fire sprinkler system. The results can be used as a foundation for more detailed future analyses that may explore design changes and applications.

Main sources of impact

Working with suppliers to identify areas where one can improve efficiency is fundamental in lowering the overall life cycle impacts of BlazeMaster®. A small proportion of the impacts are from Lubrizol's own facility, therefore, focus should be placed on improvements with raw material suppliers and ensuring best practices are in place with the pipe and fittings conversion facility.

In addition, there is little in way of improvements that can be made in the installation, use, maintenance and removal stages for BlazeMaster®, as these stages of the life cycle have virtually no impact. Further efforts to reduce waste during installation can be commended but would have little influence on the environmental impacts. Opportunities exist at end of life should the uptake of recycling be implemented – this is further discussed below.

Specific conclusions related to the components and life cycle stages are noted below.

- The impacts from the CPVC compound (cradle to grave) used for the pipe component far outweighs the impact of all other components combined (i.e., fittings, solvent cement, hangers and screws). The results indicate that the pipe component accounts for nearly 65% or more of the impact in each category. Manufacturing is the second most significant contributor, accounting for up to 29% of the total impact.

- The CPVC compound production is the most significant material that contributes to the impact. Including the fittings, the impact from the CPVC compounds account for >90% of the impact in all categories across the life cycle.

- Raw material production is the most significant contributor to all impact categories, with the exception of freshwater ecotoxicity.

Climate change and carbon footprinting

Using alternative energy and reducing greenhouse gas emissions are key challenges for the industry. Efforts to reduce the impacts of climate change should focus on the selection of raw materials with lower embedded carbon and increasing efficiency in manufacturing processes. One method to select products with a lower carbon footprint would be to consider the use of recycled products, such as recyclate or by-products from other processes.

The transport of raw materials does not have a significant impact on the global warming results; however, choosing suppliers who manufacture locally, if possible, is under Lubrizol's direct control.

Greatest potential for environmental improvement

Beyond improvements in the supply chain, analyzing environmental life cycles and reuse/recycle possibilities offers potential to reduce impacts. The sensitivity analysis clearly shows the benefits of recycling and that the more that is recovered, the better. Exploring State-level initiatives to recycle construction and demolition waste and promoting the inclusion of CPVC in these programs could open up opportunities to reduce impacts at end of life.

Although not included in this assessment, research into the inclusion of recyclate in the production of BlazeMaster® may offer further reduction opportunities.

8 GLOSSARY

Table 8.1 Glossary

Abbreviation	Full Title
ABS	Acrylonitrile-Butadiene-Styrene
ACC	American Chemistry Council
CED	Cumulative Energy Demand
CFC	Chloro-Fluoro-Carbon
CML	Centre for Environmental Sciences, Leiden University
CPVC	Chlorinated Poly-Vinyl Chloride
DOE	Department of Energy
ERM	Environmental Resources Management
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MIC	Microbiologically influenced corrosion
MSDS	Materials Safety Data Sheet
NFPA	Nation Fire Protection Agency
NREL	National Renewable Energy Laboratory
POCP	Photochemical Ozone Creation Potential
PVC	Poly-Vinyl Chloride
RDC	Regional Distribution Centre
SCAQMD	South Coast Air Quality Management District
VCM	Vinyl Chloride Monomer
VOC	Volatile Organic Compound

Annex A

Critical Review Report

CRITICAL REVIEW REPORT

LUBRIZOL

by

WALTER KLÖPFFER

LCA CONSULT & REVIEW

Frankfurt am Main

July 2010

1 CRITICAL REVIEW

1.1 Type of review

The review was conceived as a review by one independent external reviewer according to ISO 14044, section 6.2. A more demanding review according to the panel method (ISO 14044, section 6.3) was not deemed necessary, since no comparative assertions can be derived from the results of the study. The purpose of the study is to establish a Life Cycle Assessment of the BlazeMaster® CPVC pipe and fittings system used for sprinkler installations in different types of buildings. The study has been designed for use in technical information, including publications, and for improving the system under environmental aspects. Since the public, especially the technical/professional public will be informed about the results, a critical review is highly advisable in order to increase the technical quality, the compatibility with the international standards, and the credibility of the study.

The review was performed from December 2009 to June 2010 in close contact (mostly via email) with the practitioner. There was a full exchange of information from the beginning, i.e. the review of the component "Goal and Scope" (G&S), the first component of a Life Cycle Assessment study according to ISO 14040. The critical review can therefore be classified as an interactive one according to SETAC Code of practice (1993). This type of review has the advantage that typically no delay occurs in the final phase of the LCA study, in contrast to "a posteriori" reviews which are allowed by ISO (no recommendation for one or the other mode). The reviewer can furthermore influence, to a certain degree, the course of the study and is better integrated into the team compared to the a posteriori review.

1.2 Results of the review

According to ISO 14040 + 14044 (2006)

"*The critical review process shall ensure that:*

- *the methods used to carry out the LCA are consistent with the international Standard;*
- *the methods used to carry out the LCA are scientifically and technically valid,*

- *the data used are appropriate and reasonable in relation to the goal of the study;*
- *the interpretations reflect the limitations identified and the goal of the study;*
- *the study report is transparent and consistent."*

These five points can be confirmed with a few restrictions. First of all, the study has been performed according to the international standards ISO 14040 and 14044 (2006). The structure of the report reflects the structure of LCA, as codified in ISO 14040. The four components

- Goal and scope
- Inventory analysis
- Impact assessment, and
- Interpretation

were submitted for scrutiny and have been checked in detail. The G&S chapter was submitted at the beginning of the study, the other three components together with the revised G&S as part of the draft final LCA report. The methods used in this LCA study are clearly consistent with the international standards ISO 14040 + 14044 (2006).

The methods used in data collection and modeling (LCI) are described clearly and correspond to the state of the art. The product model depicts the system in sufficient detail. The Life Cycle Impact Assessment (LCIA) deals with the impact categories commonly used in similar studies and goes beyond the average. A new LCIA method, developed by one of the leading institutes in the field of LCA (CML Leiden, The Netherlands) was used. The main base-material (PVC) was considered in the past – over the whole life cycle, not so much during use, - as problematic with regard to human health and the environment. It is therefore laudable that the new LCIA was used, since it contains impact categories and indicators for these adverse effects (human toxicity, freshwater toxicity and terrestrial toxicity). Although still considered as less reliable compared to, e.g. global warming and acidification, the toxicity-related indicators should be used in cases like this one. New developments which are under way may further improve the method in the future.

The recently much discussed impact "water resources" is approximated simply by water use (taken from the life cycle inventory) and, thus, contains no scarcity factor. Inclusion of scarcity requires, of course, a regional modeling which is not standard in present LCA.
The cumulative energy demand (CED), on the other hand, is a very useful indicator, especially if split in non-renewable and renewable energy, as done in this study.

The third item (data) is the most positive aspect of this study. The so-called "foreground or primary data", collected by the commissioner and his suppliers, give a clear and quantitative picture of the product system under control by Lubrizol. For the upstream and downstream processes generic data of high quality were used. This is clearly the way each LCI should take.

Since the manufacture of the main material (PVC converted to CPVC by chlorination) contributes most to the "cradle-to-grave" impact results, a few questions had to be raised with regards to allocation methods used, since these may influence the final results. This and many other questions raised by the reviewer (on the basis of the draft final report) were answered to full satisfaction. Some inconsistencies in the PVC-chlorination data (i.e. the process in which PVC is transformed into CPVC) detected during the critical review process necessitated a re-evaluation of the data by the manufacturer. This was done and documented[1]. As it turned out, there was a misunderstanding about the terms "resin" (CPVC) and "compound" (CPVC+additives, as used for the production of BlazeMaster®).

The revised data were submitted to ERM and the practitioner included them in the final report. The differences between the data first delivered and the new ones are not negligible, but the interpretation of the results had not to be changed. Actually, the impacts calculated on the basis of the revised data indicate **lower** environmental burdens per functional unit compared to the original ones.

One exception to the generally good information offered by the commissioner to the practitioner is related to the extend to which the old mercury (amalgam) process of chlorine production

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(1) [1] Christopher Zook and Bob Vielhaber (The Lubrizol Corporation): CPVC Compound Data and Internal Verification Statement (Confidential) July 8th, 2010.

(used for PVC and chlorination of PVC) is still used in the USA and, hence, whether Hg emissions are expected to play a role in present day Life Cycle Impact Assessment of PVC and CPVC. Clearly, the obsolete amalgam process has been phasing out in recent years, but this process is not yet terminated. Once the conversion will be quantitative (and no imports from countries allowing the amalgam process occur), mercury emissions will be of no concern to PVC and PVC products, including CPVC. In the meantime, however, it should be pointed that one of the most toxic emissions (Hg) is connected with these materials, albeit (seemingly) in a non quantifiable degree.

The functional unit has been defined as a certain length of the tubes including the necessary fittings (304.8 meters = 1000 ft) providing the function of a sprinkler system for **50 years** on the average. This latter information is necessary in case the results would be used later for comparative studies. In this study, no comparisons were attempted.

The section interpretation of the report includes several sensitivity analyses. In one of them, the effect of a possible future recycling of the sprinkling tubes and fittings was explored and showed **considerable impact reduction potentials**. Since incineration is not a good alternative to land fill for PVC (due to the formation of HCl and chlorine-containing toxic organic pollutants), recycling seems to be the very best method of avoiding the deposition in landfills and, thus, not only improve the environmental end-of-life balance, but also reducing the raw material use. Raw material production has been identified as the main source of potential environmental impacts in this study, whereas the installation of the sprinkler system has a negligible impact. Thus, any reduction of the raw materials by recycling would be highly beneficial for the environmental cradle-to-grave life cycle balance.

Finally, the report is transparent and consistent. It is clearly written and well printed.

1.3 Conclusion and recommendation

The study reviewed has been accomplished according to the international standards.

The LCA results of the study show that the method is also very useful for a building product, as shown previously for other products in this application. The main improvement possibility has been identified as consequent recycling, in contrast to the still practiced method of land filling.

The conclusions and recommendations given by the authors of this report in Chapter 7 are strongly supported by this critical review.

Frankfurt am Main, July 11, 2010

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